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**PRELIMINARY RESULTS ON THE LARVAL DISTRIBUTION OF
CORYPHAENA HIPPURUS, *C. EQUISELIS*, AND OTHER
PELAGIC MANAGEMENT UNIT SPECIES IN HAWAIIAN WATERS**

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ABSTRACT

The distribution and habitat preference of larval pelagic management unit species, primarily billfishes (Istiophoridae-Xiphiidae) and dolphinfishes (Coryphaenidae) were studied off leeward Oahu in October 1987, off leeward and windward Oahu in April-May and September 1988, and off Kailua-Kona, Hawaii, in September 1988. Oceanographic data were collected with expendable bathythermographs and the conductivity temperature depth system and plankton with a Manta neuston net, a 1.8 m Isaacs-Kidd midwater trawl, and two other nets. Contour plots of surface temperature, surface salinity, and the 20°C isotherm depth were prepared for the survey areas. Contour plots of densities of plankton; fish larvae; and larval mahimahi, *Coryphaena hippurus*; pompano dolphin, *C. equiselis*; Exocoetids; and Istiophorid-Xiphiid were prepared for the survey areas.

Relationships between densities of plankton components and their physical environment were examined. Larval Coryphaenids were caught in waters with temperature of 23.7°-27.2°C and salinity between 34.67 and 35.02 ‰. Densities of Coryphaenid larvae were higher on the side of the island where a depression or doming of the 20°C isotherm depth occurred, as opposed to the uniform depth of the 20°C isotherm depth on the other side. Correlation between distance from shore and densities of mahimahi was significant ($P = 0.00$). Mahimahi densities were lower 0-40 nmi than 40-50 nmi from shore, and larvae occurred out to 70 nmi off Kailua-Kona. No correlation existed between densities of

mahimahi and plankton volumes; mahimahi occurred when plankton densities were >5 and <106 ml/1,000 m³. No relationship between densities of mahimahi and larval fishes was found, but mahimahi occurred only when larval fish densities were $<64/1,000$ m³. Occurrences of mahimahi and Exocoetids, the future predator and prey, were unassociated in the samples ($P = 0.20$), as were pompano dolphin and Exocoetids ($P = 0.08$). Despite differences in diet preference, season of increased spawning success, and oceanic distribution, the occurrences of mahimahi and pompano dolphin at sampling sites were associated ($P < 0.00$), under the same environmental conditions.

Postlarval mahimahi are neustonic and occur only near oceanic islands and over tropical continental shelves; this unique behavior simplified its assessment. Potential recruits of 2.3 and 1.38 million postlarval mahimahi were estimated for windward and leeward Oahu, respectively, in April 1988.

INTRODUCTION

Larval pelagic management unit species (PMUS)--specifically mahimahi, *Coryphaena hippurus*; pompano dolphin, *C. equiselis* (Coryphaenidae); ono, *Acanthocybium solandri* (Scombridae); and billfishes (Istiophoridae and Xiphiidae)--occur in Hawaiian waters according to studies on plankton and larval fish by King and Iversen (1962), Leis and Miller (1976), Miller et al. (1979), and Aoki and Ueyanagi (1989). Matsumoto (1967) described larval and postlarval stages of ono, based on 38 specimens caught prior to 1962 in the central Pacific, including Hawaii, and provided some information on their distribution. Information about the distribution and environment of larval billfishes in this same area was derived from specimens collected in 1950-71 by Matsumoto and Kazama (1974). Although all of these studies indicate the occurrence of PMUS larvae is rare, catch rates of some PMUS may be increased sufficiently to effectively estimate their abundance by using the information on depth distribution, diurnal migration, and seasonal occurrence provided by earlier studies and the new types of sampling gear.

Waters surrounding the Hawaiian Islands have been intensely studied by the Honolulu Laboratory (formerly Pacific Oceanic Fishery Investigations), and the Hawaii Institute of Geophysics of the University of Hawaii. An atlas by Seckel (1962) has summarized the general oceanic conditions around the Hawaiian Islands. Besides the different water masses surrounding the

islands during the year (e.g., the central North Pacific gyres and the California Current Extension), other features such as eddies and island wakes have been described (McGary 1955; Seckel 1955; Patzert 1969; Barkley 1972). Eddies are of interest because of their possible role in retaining fish larvae and their recruitment to oceanic islands (Sale 1970; Lobel and Robinson 1988; Boehlert and Mundy In press). Eddies may also concentrate prey and provide a more favorable environment for larval fish (Murdoch 1988).

In the present study, larval and postlarval mahimahi, pompano dolphin, and billfishes were collected by various types of plankton gear. The occurrence of these species relative to various elements of the physical and biological environment is shown, and densities are plotted and contoured. Finally, the possibility using neuston net tows to estimate mahimahi recruitment is discussed.

METHODS

Gear and Sampling Design

All sampling was conducted during three research cruises aboard the NOAA ship *Townsend Cromwell*: cruise TC-87-06 off leeward Oahu in October 1987 (Fig. 1); TC-88-03 Leg II off leeward and windward Oahu during April-May 1988 (Fig. 2); and TC-88-06 Leg II off leeward and windward Oahu (Fig. 3A) and off

Kailua-Kona, Hawaii, in September 1988 (Fig. 3B). Oceanographic data consisted of surface bucket temperature (measured to nearest 0.1°C), surface salinity, temperature-depth and temperature-salinity-depth profiles; these data were collected within 30 hours at each survey area on cruises TC-87-06 and TC-88-03 before biological samples were collected. On cruise TC-88-06, oceanographic data and biological samples were collected simultaneously, and all stations were completed within 48 hours at each survey area off Oahu and within 60 hours off Kailua-Kona. Salinity was determined in the laboratory with a salinometer (Autosal model 8400).

A temperature-depth profile to 450 m was obtained with an expendable bathythermograph T4 probe (XBT), and a temperature-salinity-depth profile was obtained with conductivity-temperature-depth system (CTD). On cruise TC-87-06, 9-14 XBT drops were made 2.5 nmi apart on five east-west transects which were approximately 5 nmi (5 minutes latitude) apart (Fig. 1), and CTD casts down to 500 or 1,000 m were made at the corners of the survey area as well as one approximately at the center. During cruises TC-88-03 and TC-88-06, the survey areas were expanded to 50 nmi from Oahu's shoreline and consisted of three transects 10 nmi apart (Figs. 2 and 3). On TC-88-03 XBT drops were made 10 nmi apart, except for those made 1 and 2 nmi from shore. Additional transects were added during cruise TC-88-03 after the planned survey was completed. In the leeward Oahu survey area during TC-88-03, CTD stations were again made at the corners and at the center. In the windward survey area during TC-88-03 and

in all three survey areas during TC-88-06, CTD casts were made only at 2 and 50 nmi from shore on the middle transect. Although surface bucket temperatures and salinity samples continued to be collected every 10 nmi as in previous cruises, XBT drops during cruise TC-88-06 were made 20 nmi apart on transects. The first XBT drop on adjacent transects was staggered so that the first drop was made 10 nmi offshore on the first transect, 20 nmi offshore on the second transect, and again 10 nmi offshore on the third transect. The XBT drops were dispersed approximately 14.1 nmi apart throughout the survey area.

Biological samples were collected with a Manta neuston net (Manta), a 1.8 m Isaacs-Kidd midwater trawl (IKMT), and a 3-m² neuston trawl. The Manta was a modification of that originally described by Brown and Cheng (1981): the aluminum sled had a square mouth opening (0.49 m²) and two large, fiberglass-covered urethane floats (0.5 m² X 10 cm), which were positioned to the right and left of the opening so that the top of the net opening was at sea surface. The fronts of the floats were slanted to lessen resistance and prevent diving during the tow. Attached to the sled was a 4-m-long net constructed of 333- μ m nylon mesh. The cod end was a polyvinyl chloride (PVC) tube (11.4 cm outer diameter (OD) by 37 cm in length) with 21 2.52-cm-diameter holes covered with 333- μ m nylon mesh. A two-point bridle was attached at the front of the sled's top. A General Oceanic model 2030 digital flowmeter was suspended, approximately in the center of the net opening, from the top and bottom with 45-kg test

monofilament line. Towing was done at 2-3 kn for 25 minutes from a boom at the starboard bow. The tow line and bridle usually were out of the water during the tow.

The 1.8 m IKMT was similar to that described by King and Iversen (1962). Two cruises (TC-87-06 and TC-88-03) used a green net (9 and 11.8 m in length, respectively) constructed entirely of 3.2-mm and 4.8-mm knotless nylon mesh. The net used for TC-88-06 was similar to that used for TC-88-03, except it had two sections: the first ended with a stainless steel ring (0.5 m diameter) and was coupled to the second section which had black 505- μ m nylon mesh. The cod end was a capped PVC tube (11.4 cm OD by 37 cm in length). The IKMT was towed at 2-3 kn on TC-87-06, ≤ 5 kn on TC-88-03 and TC-88-06, except during net retrieval. A flowmeter was suspended near the center of the net opening with 45-kg test monofilament. Although the amount of wire out and wire angle were used to estimate depth of the IKMT, a self-contained time-depth recorder (Benthos model No. 1170-E) was attached to the paravane to provide data on the exact net depth at time during the 30-minute tows.

The neuston trawl, similar to that designed by Shenker (1988), consisted of a galvanized 6.4 cm (inner diameter) steel pipe frame (3.5 x 1 m) with a 8.5-m long net of knotless 4.8-mm nylon mesh. A PVC bucket cod end again was used. Four inflatable spar floats (128 cm in circumference) were attached to the top edge of the frame. The bridle consisted of four lengths

of 6.4-mm diameter wire rope attached to the corners of the frames. The top (1.0 m) and bottom (1.4 m) wire ropes on each side joined at a swivel and attached to a third length (6.0 m), which in turn joined the right and left sides at a swivel at the end of the single towing line. A flowmeter also was suspended at the center of the net opening by monofilament line. The tows were 30 minutes.

A Tucker trawl, an opening and closing net with a opening of 1 m², was used twice during TC-87-06. The net was constructed of 333- μ m nylon mesh and had a PVC cod end as described above. Nets were opened and closed by a release mechanism activated by messengers on the tow line. The Tucker trawl had the advantage of a two-point bridle attached to the frame's top so that nothing was directly in front of the net. However, the proper wire angle at the desired sampling depth could not be maintained to obtain a 1-m² opening. Nets were opened for 25 minutes during tows.

With the Manta and the IKMT, biological samples were collected 10 nmi apart on the middle transect, except at stations 1 and 2 nmi from shore. Two additional transects perpendicular to the shoreline were made during TC-87-06 and TC-88-03. Manta and IKMT tows at night were made at 2000-0500 hours; Manta tows during the day were made at 0745-1700 hours. Oblique tows from 50 m deep to the surface were made with the IKMT during cruises TC-88-03 and TC-88-06. For cruise TC-87-06, horizontal IKMT tows at the surface and at 25 and 50 m were made at nearly all

stations; additional tows to 80 m were made at a few stations. Sometimes the IKMT tows, which required 50 m depth, were canceled at stations 1 nmi from shore. All samples were fixed in 75% ethanol at sea; in the laboratory, the fixative was replaced by a 70% solution for storage.

Sample Processing

Samples were sorted within a year after the cruises. For a rough measurement of zooplankton biomass, wet zooplankton volume was determined by displacement. Prior to the volume of zooplankton being measured, debris (e.g., wood chips, plastics, tar balls, feathers, and >3-cm fish) were removed from the sample. After the ethanol had been removed with a strainer (333- μ m nylon mesh), zooplankton volume was measured by displacement in either a 100- or 500-ml graduated cylinder, depending on the amount of zooplankton in the sample.

Fish larvae were systematically sorted and processed. All fish larvae were first separated from the zooplankton sample and counted; then, all Coryphaenids, Istiophorids-Xiphiid, and Exocoetids (halfbeaks and flying fishes) were separated and counted. Coryphaenids and Istiophorids-Xiphiid were identified to species; lengths were measured with an ocular micrometer or a dial caliper, depending on the size of the specimen. Coryphaenids were classified as larvae if they had a notochord length (NL) of <11 mm, or as postlarvae if ≥ 12 mm fork length

(FL). At around 12 mm in length, finray counts are comparable to adult counts, the caudal fin begins to fork, the body becomes pigmented, bands appear on the sides (Konishi 1988), and the fish becomes neustonic (Aoki and Ueyanagi 1989).

Data Processing

Since tows strained different amounts of water, catch rates were standardized (CPUE). Zooplankton volume, number of fish larvae, and number of PMUS larvae by individual species or species group in a sample were standardized to volume or number per 1,000 m³ water strained as an index of density. For postlarval mahimahi and flying fishes, almost all of which were neustonic, catch per 1,000 m² of surface area was also calculated for contouring. Data were sorted by cruise, study area (windward Oahu, leeward Oahu, and Kailua-Kona, Hawaii), day or night sampling, and distance from shore (i.e., 1, 2, 10, 20, 30, 40, and 50 nmi).

Catches from the Manta, the IKMT, and the neuston trawl were compared using samples collected during TC-87-06. At each location, a surface tow was made using each gear type. Zooplankton volume and densities of all fish larvae and Coryphaenids only were compared using the Kolmogorov-Smirnov two-sample test. To compare the length-frequency distribution of Coryphaenids caught with the three gear types, lengths of both

species were combined to obtain an adequate sample size. Lengths of Coryphaenids caught in the IKMT and the neuston trawl were also combined to compare with the length-frequency distribution from the Manta, by using the Kolmogorov-Smirnov two-sample test.

Relationships between components of day and night plankton samples and physical environmental factors of TC-88-03 and TC-88-06 were examined using correlation statistics for all samples including zero catches. Plankton components included zooplankton volume and larvae densities of mahimahi, pompano dolphin, flying fishes and halfbeaks, billfishes, and all fishes combined. Physical factors included surface temperature, surface salinity, and distance from shore. Relationships where significant correlations occurred were examined further for clarification. Independence of plankton components was tested with two-way contingency tables; density was classified as zero or non-zero catch.

Day-night comparisons were made for plankton component catches by the Manta at each sampling location for cruises TC-88-03 and TC-88-06. As above, plankton components consisted of zooplankton volume and fish larvae densities. The frequency distributions of zooplankton volume and of larvae densities by species, species groups, and all species combined were examined for normality. The frequency distributions of zooplankton volume and of larvae densities were skewed and required $\log(n + 1)$ transformation for normalization. Group mean densities were

compared by *t*-test. As appropriate, relationships were examined by simple linear regression. The Kolmogorov-Smirnov two-sample test was also used to compare day-night samples. Other components, such as mahimahi and pompano dolphin, were not present in every sample. In these cases, the only locations used had either day or night sampling with a non-zero value. Frequency distributions of these components were compared for day-night differences using the Kolmogorov-Smirnov two-sample test.

Diurnal variations in plankton volumes were standardized by fitting the distribution of plankton volume by time of day to a sine wave (King and Hida 1954). Since the Manta tows were 25 minutes long, 12.5 minutes was added to the start time to obtain the midpoint tow time. This time was then converted to a sine function where 0000 hours equaled 1; 0600 hours, 0; 1200 hours, -1; and 1800 hours, 0. Then the adjusted plankton volume was estimated from a linear regression of log of plankton volume on sine function. Unlike King and Hida (1957) who standardized sine to equal zero, we standardized to midnight (sine = 1), when catch was greatest. The adjusted plankton volume was obtained from the following:

$$\hat{Y}_{a,1} = \bar{Y}_0 + (Y_x - Y_1);$$

where $\hat{Y}_{a,1}$ is adjusted plankton volume, \bar{Y}_0 is mean plankton volume, Y_x is observed plankton volume, and Y_1 is estimated plankton volume at midnight. Data from all cruises were adjusted accordingly.

After the data were sorted and standardized, surface temperature, surface salinity, 20°C isotherm depths, zooplankton volume, and densities of fish larvae, mahimahi, pompano dolphin, and Exocoetids were contoured for each survey by personal computer (PC) software, SURFER Version 4 (Golden Software 1989). To examine the relationships, densities of mahimahi, pompano dolphin, and billfishes were posted on contour charts of their physical and biological environment.

Contour charts of the postlarval mahimahi densities were used to estimate potential recruits. The areas of contour levels at 0.1/1,000 m² intervals of surface area were estimated using SURFER Version 4 software (Golden Software 1989) for the PC. The area was estimated as a percentage of a degree square and converted to square meters. The number of postlarvae at each contour level was estimated by multiplying the area of the contour interval by the mean density of the bordering contour lines (i.e., 0.15/1,000 m² of surface area times the area between contour lines of 0.1 and 0.2). Estimates were not made at levels below 0.1/1,000 m² of surface area.

RESULTS

Physical Environment

An oceanographic survey was conducted at the beginning at each survey. Figures 4-9 present the surface temperature, surface salinity, and the 20°C isotherm depth contours for selected survey areas from each cruise. Salinity was not determined for all seawater samples collected during TC-88-06, because of a breakdown of the salinometer; therefore, surface salinity was not plotted for this cruise. Sea surface temperatures off leeward Oahu in April 1988 (Fig. 6A) were slightly lower over the submerged Kaena Point ridge northwest of Oahu.

A dome of the 20°C isotherm depth formed off leeward Oahu in October 1987 (Fig. 4C) and September 1988 (Fig. 7B) and off Kailua-Kona, Hawaii in September 1988 (Fig. 9B). In April 1988, a depression of the 20°C isotherm depth appeared off windward Oahu (Fig. 5C). Depth of the 20°C isotherm off leeward Oahu in April 1988 and windward Oahu in September 1988 was consistent at about 170 m, which is the mean depth of the 20°C isotherm in Hawaiian waters (Patzert 1969). Because of the uniformity, the 20°C isotherm depth could not be contoured.

Comparison of Catch by Gear

The feasibility of using all these gear types--Manta, IKMT, neuston trawl, and the Tucker trawl--for biological sampling was evaluated during cruise TC-87-06. Before comparisons could be made, catch data were standardized. A need to expand the survey area was recognized after cruise TC-87-06, so the Manta and the IKMT were selected to conduct the biological surveys at the surface and in the water column, respectively, on the remaining two cruises. The survey of the expanded areas using just these two gears types was completed without requiring additional time.

Comparing surface catches of the Manta, the IKMT, and the neuston trawl on TC-87-06 may be moot as these gears types varied in mesh size. The frequency distributions of zooplankton volume (Kolmogorov-Smirnov two-sample test, $P < 0.01$) and the CPUE of fish larvae caught by the Manta and the IKMT, respectively ($P < 0.01$), were significantly different. Likewise, the frequency distributions of zooplankton volume ($P < 0.01$) and the CPUE of fish larvae ($P < 0.01$) from the Manta and the neuston trawl samples also were significantly different. As expected, no significant difference was found in the frequency distributions of zooplankton volume ($P > 0.4$) and the CPUE of fish larvae ($P = 1.0$) between the IKMT and the neuston trawl samples. The neuston trawl, however, caught slightly more larval and postlarval Coryphaenids and Exocoetids than the IKMT at the surface.

Differences in size selectivity of Coryphaenid by the Manta, the IKMT, and neuston trawl were expected. To increase the number caught by the IKMT for the comparison, both Coryphaenid species were used; their morphology is similar, so gear selectivity should be similar, if not identical, for both species. Because both gears types were the same mesh size and material and had similar catches of zooplankton volume and densities of fish larvae, the catches of Coryphaenids by the neuston trawl and IKMT were combined. The length range of the primary target species, the Coryphaenids, was 3.4-27.7 mm NL or FL for the IKMT and neuston trawl (Fig. 10A); the Manta caught Coryphaenids of 4.8-47.5 mm NL or FL (Fig. 10B). Both the Manta and the IKMT and neuston trawl caught some larval Coryphaenids, but the Manta caught larger specimens than the other two trawls which were towed faster, had larger net openings, and were constructed of netting with larger mesh sizes.

Relationship of Plankton Components to Physical Environment

Before the relationship of plankton components to their biological and physical environment was examined, the standardized data were sorted. Table 1 presents the correlation analyses of the densities of zooplankton, fish larvae and mahimahi, pompano dolphin, Exocoetids, and billfishes caught in day and night samples; surface temperature; surface salinity; and distance from shore. There appeared to be 24 significant

correlations; however, many resulted from the manner in which zero catches were distributed.

Day-Night Differences in Catch

Day-night differences in catch were examined to determine whether diurnal migration or day-night differences in catchability affected the density estimates. The variances of zooplankton volumes and larval fish densities in day-night samples were homogeneous: $P = 0.82$ and $P = 0.19$, respectively. Mean zooplankton volumes for day-night samples were significantly different ($P < 0.001$). The linear relationship of log zooplankton volumes in day-night samples was not significant ($P = 0.19$). A plot of zooplankton volume at time of day appeared to vary cyclically (Fig. 11); consequently, the densities were fitted to a sine wave to correct for diurnal variation (Fig. 12). Mean densities of larval fish collected in day and night did not significantly differ ($P = 0.15$). A linear regression of log larval fish densities at day and night also was not significant ($P = 0.72$).

Day-night differences in densities of larval and postlarval mahimahi and pompano dolphin taken in Manta net tows during April-May and September 1988 were examined because they had the largest sample sizes among the PMUS. The mean density of larval and postlarval mahimahi in day tows ($0.25/1,000 \text{ m}^3$ of water) was less than that of night tows ($0.34/1,000 \text{ m}^3$ of water). The

differences between mean densities of larval and postlarval pompano dolphin were greater in night tows ($1.09/1,000 \text{ m}^3$ of water) than in day tows ($0.27/1,000 \text{ m}^3$ of water). The frequency distributions of larval and postlarval mahimahi and pompano dolphin in day-night Manta net tows were significantly different when compared using the nonparametric Kolmogorov-Smirnov two-sample test. Using a two-way contingency table test, the occurrence of pompano dolphin in day-night catches was found to be associated ($P < 0.01$), whereas occurrence of mahimahi in day-night catches was not ($P = 0.13$). With non-zero samples, mahimahi occurred at only three sites in the day-night samples, whereas pompano dolphin occurred in both samples at seven sites. Day-night densities of mahimahi were combined in later analyses; however, only night densities of pompano dolphin were used in subsequent analyses.

The mean density of Exocoetids was $0.22/1,000 \text{ m}^3$ of water in day samples and $0.37/1,000 \text{ m}^3$ of water in night samples. Differences in frequency distribution and mean density were highly significant ($P = 0.00$). Day-night densities were also unassociated (contingency table test, $P = 0.92$) since Exocoetids occurred in the day-night samples at only one site. Therefore, their densities were low and patchy. In subsequent analyses, day-night densities were combined.

All but one billfish larva caught by Manta were captured during the day in April-May and September 1988, but several were

caught subsurface with the IKMT at night. Larval billfishes were caught too infrequently to be analyzed.

Relationship of Coryphaenids to Their Environment

The relationship of Coryphaenids to their environment was examined to further define their habitat. Zooplankton volumes were 1-122 ml/1,000 m³ of water in the surveys, with mahimahi occurring when zooplankton volumes were >5 and <106 ml/1,000 m³ of water. Larval fish densities were 1 to 100/1,000 m³ of water in the surveys, with mahimahi occurring when larval fish densities were <64/1,000 m³ of water.

The relationships of densities of mahimahi, pompano dolphin, and Exocoetids to each other were examined using a two-way contingency table test. Densities of mahimahi and pompano dolphin were associated ($P < 0.01$), but were independent of Exocoetids densities ($P = 0.20$ and $P = 0.08$, respectively).

Correlation between densities of mahimahi and distance of the tow from shore was significant (Table 1), with greater densities occurring farther than 30 nmi from shore. However, a nine-by-two contingency test showed independence between the occurrence (i.e., presence or absence) of mahimahi and distance from shore ($P = 0.14$).

Distribution of Various Catch Components in Survey Areas

Charts of contoured density data aid in visualizing the distribution. Contours of Manta zooplankton volumes corrected for diurnal variation were plotted by survey area for October 1987 and April-May 1988 (Figs. 13-14). Densities of pompano dolphin caught off leeward Oahu by the Manta in October 1987 were also contoured (Fig. 15); densities of plankton components for September 1988 were not.

The posting of densities of one plankton component onto the contour chart of another facilitates the visual comparison for recognizing relationships and trends. Day-night densities of larval and postlarval mahimahi and night densities of larval and postlarval pompano dolphin were posted on contours of the following: actual densities of zooplankton; day-night densities of all fish larvae, Exocoetids, and mahimahi; surface temperatures; and surface salinities for October 1987 and April-May 1988 (Figs. 16-20). Day-night densities of mahimahi and pompano dolphin were posted on contours of surface temperature and the 20°C isotherm depth for September 1988 (Figs. 21-24). Densities of larval billfishes were also plotted on surface temperature contours off leeward Oahu for September 1988 (Fig. 25). Contour plots were not made when non-zero density data were limited, as was the case for Exocoetids in April 1988 and for Coryphaenids off windward Oahu in September 1988.

Because of very small catches of plankton by surface and oblique IKMT tows, plankton and larval fish components were not plotted. The larger mesh used on IKMT and the neuston trawl was not designed to catch plankton or fish larvae. Catches of postlarvae were surprisingly low for the amount of water strained per tow. Subsurface tows were directed primarily at larval ono (*Acanthocybium solandri*), but none was caught.

Estimates of Mahimahi Recruits

Because of the unique reproductive behavior of adults and their neustonic postlarval stage, estimating mahimahi recruits to an oceanic island fishery is greatly simplified. Using contours of postlarval mahimahi density, estimates of 2.38 million and 1.38 million postlarvae were obtained for survey areas off windward and leeward Oahu, respectively, during April-May 1988 (Fig. 26).

DISCUSSION

Day-Night Differences in Samples

Although day-night differences appeared to occur in all components of the plankton, they were statistically significant in only zooplankton volume and densities of mahimahi and pompano dolphin. The increase in surface zooplankton at night was due to the migration of various crustaceans, fishes, and other organisms

from the midwater depths. King and Hida (1954) fitted a sine wave to a plot of the log zooplankton volume on time of tow to adjust for diurnal variation. When the log zooplankton volumes from April-May and September were plotted on time of tow converted to sine functions, the linear relationship had a positive slope that was significantly different from zero. After being standardized to midnight, high or low densities were still apparent (Figs. 13-14).

Differences in day-night densities of the Coryphaenids can be attributed to gear avoidance. Some postlarval pompano dolphin were collected in subsurface tows by Aoki and Ueyanagi (1989); however, the larger postlarvae occurred closer to the surface in the vertical distribution. Aoki and Ueyanagi (1989) concluded that since postlarval mahimahi and pompano dolphin were neustonic, the decrease in density during daylight was due to avoidance. Larval and postlarval mahimahi and pompano dolphin occurred more frequently in night samples than in day samples. These differences can be attributed partly to gear avoidance and to patchiness and low density. As a consequence, surface day tows probably underestimated the density. However, even though day-night samples of mahimahi at the same location were not statistically associated, they were combined to more completely define distribution.

Insufficient data were obtained on the distribution of billfishes. Night surface samples of billfishes are not

reliable, because most billfishes submerge at night. Only one billfish larva was caught by the Manta net at night, whereas a number were caught by the IKMT in oblique tows. Vertical migration by billfish larvae was previously reported by Ueyanagi (1964) and by Leis et al. (1987).

Physical Environment of Larval and Postlarval Coryphaenids

Larval and postlarval mahimahi and pompano dolphin were caught in waters of 23.7-27.2°C and salinity of 34.67-35.02 ‰. Surface water temperature was 23.5-25.2°C in April-May 1988 and 26.3-27.4°C in September 1988; salinity was 34.67-35.28 ‰ in October 1987 and in April-May and September 1988. Thus, larval and postlarval Coryphaenid occurred in waters with temperatures and salinities covering most of the survey ranges and neither mahimahi nor pompano dolphin densities correlated with sea surface temperature or salinity (Table 1). However, most of the pompano dolphin were caught in 26.7-27.2°C surface seawater, which was prevalent in September-October, and they were relatively abundant off Kailua-Kona, Hawaii.

Larval and postlarval Coryphaenids appeared to be more abundant on the side of the island where the 20°C isotherm depth formed either a dome or depression. In April-May 1988, there were more Coryphaenids on the windward side of Oahu where a depression of the 20°C isotherm depth occurred as opposed to the leeward side where few larvae were caught except for one large

catch made along a debris line. No significant elevation or depression of the 20°C isotherm depth occurred on the leeward side. In September 1988, elevations of the 20°C isotherm depth occurred off leeward Oahu and Kailua-Kona, Hawaii, where larval Coryphaenids were caught. Off windward Oahu that September, the 20°C isotherm depth remained close to 170 m throughout the survey area and no Coryphaenid was caught. Although larval and postlarval Coryphaenids were more abundant on the side of the island where the 20°C isotherm depth formed a dome or a depression, none were caught directly over such structures.

Larval distribution is a major difference between the occurrence of mahimahi and pompano dolphin. Shcherbachev (1973) and Aoki and Ueyanagi (1989) reported that mahimahi larvae were found near oceanic islands and on the continental shelf, but not in the open ocean. Larval mahimahi also occur only in the coastal surface water off southern Japan (Konishi 1988). In our survey, mahimahi occurred at stations 1 nmi from shore and have been reported closer to shore (Miller et al. 1979). Postlarval mahimahi have also been collected at the shoreline of windward Oahu when these neustons were blown to shore by strong northeast trade winds during a full moon (R. K. Burch, formerly with the Waikiki Aquarium, 2777 Kalakaua Ave., Honolulu, HI 96815, pers. commun., 1982). In the present study, there was a correlation between mahimahi density and the distance from shore. Mahimahi were caught more frequently and in greater numbers 40-50 nmi off Oahu and out to 70 nmi off Kailua-Kona, Hawaii. Our survey,

however, did not extend far enough from the islands to determine the outer limits of the larval mahimahi habitat. Larval pompano dolphin on the other hand have been found in the open ocean, as well as near oceanic islands and on the continental shelves (Shcherbachev 1973; Aoki and Ueyanagi 1989; Fedoryako 1989). Off southern Japan, larval pompano dolphin occur beyond coastal waters (Konishi 1988). In our study, pompano dolphin occurred at all distances from shore, and there was no correlation between density of pompano dolphin and distance from shore (Table 1).

The predator-prey relationship between Coryphaenids and flying fishes was thought to develop early in life. Breder (1932) observed predation on a 12-mm larval flying fish, *Cypselurus* sp., by a 26-mm mahimahi in a tank. However, no correlation existed between densities of Exocoetids and mahimahi or pompano dolphin (Table 1). The occurrence of Exocoetids was associated with neither mahimahi nor pompano dolphin in the Manta samples. Coryphaenids and Exocoetids usually occupied different locations (Figs. 16E, 17E, and 18E). For adult mahimahi in Hawaiian waters, flying fishes are one of the primary prey (Welsh 1950; Tester and Nakamura 1957). Flying fishes, however, were not a common prey item in stomach contents of 53 adult pompano dolphin collected in the central Pacific (Rothschild 1964).

Relationships between densities of mahimahi or pompano dolphin to densities of plankton or fish larvae differed because of feeding habits. However, these differences did not always

appear in the correlation analyses (Table 1). Scherbachev (1973) found that mahimahi larvae feed mainly on crustaceans, primarily copepods. But no correlation existed between the densities of mahimahi and plankton in our samples. Postlarval pompano dolphin in our samples fed on copepods and small mysids (unpubl. data); this was consistent with the correlation of densities of plankton to pompano dolphin. Earlier attempts to relate larval tuna densities to zooplankton volume also showed no correlation (King and Hida 1957; Strasburg 1960). Coryphaenids in our samples, like the tuna larvae in earlier studies, occurred only when the zooplankton volume was >5 or <106 ml/1,000 m³ water strained. No correlation was found between the densities of mahimahi and fish larvae. Gibbs and Collette (1959) and others found that fish constituted the major portion of mahimahi diet. Shcherbachev (1973) reported that a change in feeding habits to piscivore occurred at about 20-mm standard length. Kojima (1961) found that fishes in stomach contents of Coryphaenids were associated with the sea surface. Since most of larval mahimahi collected were <20 -mm FL, their association with larval fish may not yet have developed. Densities of pompano dolphin correlated with densities of fish larvae in day samples only. Relating Coryphaenid densities to day forage densities may be more appropriate since feeding occurs during the day and the circadian periods. It may be difficult to correlate with zooplankton and fish larvae because they are composites consisting of a large and variable number of species whose densities change from location to location and from season to

season. Therefore, it would be difficult to relate the densities of mahimahi to the densities of zooplankton or of fish larvae. Secondly, low zooplankton densities may have occurred in areas of new upwelling, and the zooplankton biomass had not yet developed. In areas of high zooplankton biomass, the postlarvae may have grown large enough to evade the gear.

Although larval and postlarval mahimahi and pompano dolphin differ in food preference, season for greater spawning success, and oceanic distribution, they occurred under similar environmental conditions. The occurrences of mahimahi and pompano dolphin were associated at the sampling sites ($P < 0.00$), and the correlation of their densities was highly significant ($P = 0.00$). Both species occurred in 12 of 35 non-zero catch samples and appeared to prefer similar environmental conditions.

Postlarval Coryphaenids reportedly are associated with floating algae and other debris (Springer and Bullis 1956; Uchida and Shojima 1958; Gibbs and Collette 1959; Konishi 1988). In our study, postlarval Coryphaenids were abundant in tows along the transect line off leeward Oahu through an area known for the occurrence of a line of debris (i.e., small (<3 cm) pieces of wood, plastic foam, feathers, and tar balls). A single tow caught 15 postlarval Coryphaenids; however, repeated tows at that location yielded no additional catch. Evidently, patches of larval mahimahi are small in area, and this large catch may have been anomalous, made during the corpuscular period. Patchiness

can also be assessed by the occurrence of larval and postlarval mahimahi in day-night samples at only 3 of 16 locations where they were caught and by their occurrence in catches at adjacent stations. The patchiness may be due to the generally low density of Coryphaenids where there is little chance of capture in each tow.

Seasonal Trends of PMUS

Densities of PMUS were examined for seasonal trends. Although postlarval mahimahi are found throughout the year off Oahu (R. K. Burch, pers. commun., 1982), they were relatively more abundant in our April samples. Mahimahi larvae are found in coastal waters of southern Japan throughout the year and are most abundant during May-September (Konishi 1988). Postlarval pompano dolphin also have been collected throughout the year off Oahu (R. K. Burch, pers. commun., 1982) but were relatively more abundant in our September and October samples. Larval shortbill spearfish, *Tetrapturus angustirostris*, were collected on all cruises. In Hawaiian waters, Matsumoto and Kazama (1974) reported an association of larval shortbill spearfish with surface water temperature of $>24^{\circ}\text{C}$, which was well below the minimum sea surface temperature (24.7°) in our study. Larval Pacific blue marlin, *Makaira mazara*, were found in September, coinciding with the pattern of occurrence previously reported for Hawaiian waters by Matsumoto and Kazama (1974). Larval swordfish, *Xiphias gladius*, occurred in April, again in agreement

with Matsumoto and Kazama (1974). A billfish larva tentatively identified as a striped marlin, *T. audax*, was found in our April sampling, when ovaries in adults are developed for spawning in Hawaiian waters (unpubl. data).

Although no ono larva was collected on our cruises, single specimens were collected in the same survey areas 10 days before our cruises in April and September 1988 (B. C. Mundy, Honolulu Laboratory, pers. commun., 1990).

Comparisons of Length-Frequency Distributions of Larval Coryphaenids Caught by Manta Net, IKMT, and Neuston Trawl

The occurrence of postlarval specimens of >25 mm FL in the Manta catches was unexpected, because the neuston trawl and IKMT with nets of larger mesh did not catch such large specimens (Fig. 10). The higher CPUE for Coryphaenids by the Manta can be attributed to differences in towing speed and bridle configuration. Munk (1988) demonstrated that catch per unit volume decreased to one-third when speed of the IKMT was increased from 2.5 to 3.5 kn and that larger larvae were caught at the slower speed. Also, both the IKMT and the neuston trawl have bridles in front of the net openings; this may have alerted the postlarvae of the net. The Manta, when properly towed and in moderate seas, has the bridle and tow line out of the water.

The presence of postlarval Coryphaenids in the subsurface IKMT tows may be due to contamination at the surface because the IKMT is not an open and closing net. On the other hand, Aoki and Ueyanagi (1989) reported that pompano dolphin of >10 mm FL did occur in subsurface day catches.

Estimating Recruitment of Mahimahi from Plankton Samples

Estimating standing stocks of larval PMUS by examining the plankton samples appears to be possible for mahimahi only. Based on the contours of postlarval mahimahi densities in Figure 26, there were an estimated 2.3 million postlarval mahimahi in the survey area off windward Oahu and 1.38 million off the leeward side. Not included in the estimates are the postlarvae east of longitude 157°W, north of latitude 22°N of the windward Oahu survey area, and west of 159°W longitude of the leeward Oahu survey area. These estimates obviously are crude, because the cruises were designed to address a number of biological, environmental, and gear issues, not to estimate larval standing stock. Nonetheless, it may also be feasible to estimate the standing stock of postlarval mahimahi because (1) spawning apparently occurs only around oceanic islands and not in the open ocean (Shcherbachev 1973; Aoki and Ueyanagi 1989), (2) postlarval mahimahi are neustonic (Aoki and Ueyanagi 1989); and (3) postlarvae are easily identifiable. Thus, the sampling area can be well-defined and limited to surface water around oceanic islands, making a complete census of a cohort feasible. If

mahimahi reproduction in the mid-ocean occurs only in insular areas, the progeny may remain associated with or return to the same islands to spawn as adults and become available to the commercial and recreational fisheries. Thus, it may be possible to relate within-season larval mahimahi production to the birth-date frequency of new recruits to the Hawaiian fishery. Estimating the recruitment of pompano dolphin from plankton would not be feasible because of their extensive spawning area and diurnal behavior.

Several variables still must be determined before a complete census can be undertaken. First, the distance from shore where postlarval mahimahi cease to occur must be determined, because postlarvae were still present in samples collected 50 nmi off Oahu and 70 nmi off Kailua-Kona. Second, night catches were slightly larger than day catches, so avoidance of postlarvae to the Manta should be examined. Third, Aoki and Ueyanagi (1989) did not sample the water column between 20 m and the surface, and some postlarvae may submerge during the day. Fourth, gear that could catch more postlarvae per tow is desirable. Finally, a program to determine recruit density (CPUE) and birth-date distribution would need to be conducted concurrently with an ichthyoplankton survey to investigate mahimahi recruitment.

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Table 1.--Catches during cruise TC-87-06 off leeward Oahu in October 1987.

Sta. no.	Lat. °N	Long. °W	Depth m	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena</i> <i>hippurus</i>	<i>C.</i> <i>equiselis</i>	Flying fishes	Bill- fishes
Manta Net										
9	21.418	158.477		1,072	14.0	44.8	0.00	0.00	0.00	0.00
15	21.418	158.207		1,033	67.7	38.7	0.00	0.00	0.00	0.00
17	21.421	158.210		1,041	11.5	15.4	0.00	1.92	0.00	0.00
27	21.424	158.253		1,003	14.9	118.5	0.00	0.00	0.00	0.00
32	21.408	158.340		1,029	46.6	54.4	0.00	0.00	0.00	0.00
39	21.421	158.490		973	51.4	37.0	0.00	4.11	1.03	0.00
46	21.418	158.688		1,024	39.0	33.2	0.00	3.90	0.00	0.00
52	21.254	158.194		1,029	19.4	117.5	0.00	0.00	0.00	0.97
64	21.486	158.290		1,071	42.0	21.5	0.00	0.93	0.93	0.00
75	21.519	185.512		1,032	23.2	104.6	0.00	0.00	0.00	0.00
81	21.594	158.689		769	15.6	128.7	0.00	0.00	0.00	0.00
88	20.996	159.012		815	14.7	17.2	0.00	0.00	1.23	0.00
93	21.266	158.677		1,092	18.3	183.9	0.92	0.00	0.00	0.00
94	21.255	158.530		993	20.1	31.2	0.00	0.00	0.00	0.00
Isaac-Kidd Midwater Trawl										
13	21.414	158.203	1	8,856	0.1	1.1	0.00	0.00		0.00
18	21.419	158.210	1	5,727	2.8	0.5	0.17	0.00		0.00
19	21.415	158.209	25	8,971	3.1	5.2	0.00	0.00		0.00
20	21.426	158.211	50	7,080	1.4	2.7	0.00	0.00		0.00
23	21.433	158.251	50	5,544	1.8	0.9	0.00	0.00		0.00
24	21.433	158.257	25	7,205	0.6	3.2	0.00	0.00		0.00
25	21.424	158.254	1	5,414	0.4	1.5	0.00	0.00		0.00
28	21.418	158.335	50	7,843	3.8	0.1	0.00	0.00		0.00
29	21.435	158.343	25	6,894	4.6	2.9	0.00	0.00		0.00
30	21.409	158.334	1	6,863	3.6	0.0	0.00	0.00		0.00
35	21.419	158.498	50	8,184	3.7	1.0	0.00	0.00		0.00
36	21.430	158.483	25	7,842	2.8	5.4	0.00	0.00		0.00
37	21.423	158.488	1	13,117	0.6	3.0	0.00	0.00		0.00
42	21.420	158.662	50	18,655	0.6	1.6	0.00	0.00		0.00
43	21.416	158.693	25	9,475	1.1	2.5	0.00	0.00		0.00
44	21.425	158.663	1	8,177	1.0	1.3	0.00	0.00		0.00
48	21.254	158.190	50	13,271	7.8	0.0	0.00	0.00		0.00
49	21.254	158.227	25	11,441	1.7	0.7	0.00	0.00		0.00
50	21.253	158.195	1	12,105	5.0	0.7	0.00	0.00		0.00
59	21.517	158.294	80	16,370	4.6	0.5	0.00	0.00		0.00
60	21.478	158.292	50	13,419	3.7	0.7	0.00	0.00		0.00
61	21.518	158.290	25	12,708	2.0	0.5	0.00	0.00		0.00
62	21.487	158.293	1	11,620	2.4	0.0	0.00	0.00		0.00
70	21.596	158.490	80	12,561	12.7	1.1	0.00	0.00		0.00
71	21.601	158.525	50	12,673	3.9	0.6	0.00	0.00		0.00
72	21.594	158.475	25	13,333	3.7	0.5	0.00	0.00		0.00
73	21.581	158.517	1	11,422	0.9	0.4	0.00	0.00		0.00

Table 1.--Continued.

Sta. no.	Lat. °N	Long. °W	Depth m	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena</i> <i>hippurus</i>	<i>C.</i> <i>equisetis</i>	Flying fishes	Bill- fishes
76	21.581	158.652	80	11,610	7.8	0.5	0.00	0.00		0.00
77	21.576	158.680	50	9,692	3.1	1.3	0.00	0.00		0.00
78	21.570	158.652	25	11,033	1.8	0.3	0.00	0.00		0.00
79	21.589	158.683	1	7,253	1.4	0.1	0.00	0.00		0.00
83	20.998	158.989	65	11,493	2.2	1.9	0.00	0.09		0.00
84	20.999	159.028	40	13,412	3.0	1.2	0.00	0.00		0.00
85	20.997	158.995	25	12,349	2.4	0.8	0.00	0.00		0.08
86	20.992	159.029	1	10,447	0.4	0.2	0.00	0.00		0.00
90	21.242	158.686	50	12,972	2.7	2.2	0.00	0.00		0.00
Neuston Trawl										
16	21.417	158.211		8,904	6.2	0.9	0.00	0.22	0.00	0.00
26	21.425	158.256		7,428	1.1	0.0	0.00	0.13	0.00	0.00
31	21.425	158.337		8,705	2.3	0.0	0.00	0.00	0.00	0.00
38	21.418	158.494		9,826	1.5	6.4	0.00	0.00	0.00	0.00
45	21.437	158.657		11,033	6.3	0.6	0.09	0.00	0.00	0.00
51	21.255	158.222		12,089	3.3	0.5	0.00	0.00	0.00	0.00
63	21.517	158.292		12,314	1.6	0.5	0.08	0.08	0.00	0.00
74	21.579	158.471		12,972	1.5	0.9	0.00	0.00	0.00	0.00
80	21.607	158.673		15,300	3.3	0.1	0.00	0.00	0.00	0.00
87	20.989	158.987		11,230	0.5	0.4	0.00	0.00	0.00	0.00
92	21.258	158.695		9,765	0.6	0.2	0.00	0.00	0.00	0.00
95	21.257	158.510		10,744	0.6	0.0	0.00	0.00	0.00	0.00
Tucker Trawl										
40	21.422	158.498	50	----	(60)	(316)	(0)	(4)		(0)
41	21.425	158.478	25	1,872	0.53	1.6	0.00	0.00		0.00

Table 2.--Catches during cruise TC-88-03 off leeward and windward Oahu in April 1988.

Sta. no.	Time of day	Lat. °N	Long. °W	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena hippurus</i>	<i>C. equiselis</i>	Flying fishes	Bill-fishes
Manta Net										
5	1341	21.069	158.536	815	49.09	15.95	0.00	0.00	0.00	0.00
12	1558	20.918	158.480	755	105.92	22.51	5.30	0.00	0.00	0.00
33	1719	21.531	157.638	680	26.46	51.44	0.00	0.00	0.00	0.00
40	1205	21.630	157.288	942	11.67	18.04	0.00	0.00	0.00	0.00
53	1056	21.555	157.723	700	1.43	4.29	0.00	0.00	0.00	0.00
55	1740	21.619	157.650	617	30.77	40.49	0.00	1.62	0.00	0.00
62	2314	21.918	156.967	928	37.71	25.86	2.15	0.00	0.00	0.00
64	213	21.831	157.143	979	35.74	93.94	0.00	0.00	0.00	0.00
66	435	21.736	157.310	852	58.69	62.21	0.00	0.00	1.17	0.00
67	917	21.481	157.743	1,387	1.44	3.61	0.00	0.00	0.00	0.00
68	1005	20.508	157.704	1,210	2.48	11.57	0.00	0.00	0.00	0.00
69	1058	21.550	157.626	1,168	17.13	31.69	0.00	0.00	0.00	0.00
70	1223	21.641	157.483	847	5.90	9.45	0.00	0.00	0.00	0.00
71	1353	21.719	157.332	1,008	5.95	0.99	0.00	0.00	0.00	0.00
72	1531	21.823	157.169	939	5.33	13.85	2.13	0.00	0.00	0.00
73	1706	21.924	157.000	778	32.15	45.00	5.14	0.00	0.00	1.29
74	2029	21.647	157.471	709	126.92	31.03	0.00	1.41	1.41	0.00
76	2306	21.551	157.629	520	76.91	11.54	0.00	0.00	0.00	0.00
79	157	21.528	157.733	700	42.86	48.57	0.00	0.00	0.00	0.00
80	247	21.484	157.744	839	50.04	75.06	0.00	0.00	0.00	0.00
84	2158	21.674	157.886	813	51.64	31.96	0.00	0.00	0.00	0.00
87	121	21.753	157.765	868	46.08	14.98	0.00	0.00	0.00	0.00
90	447	21.850	157.621	1,130	66.38	26.55	2.66	0.00	0.00	0.00
91	1413	21.752	158.001	960	20.82	41.65	0.00	0.00	0.00	0.00
92	1506	21.802	158.002	1,042	19.19	20.15	0.96	0.96	0.00	0.00
93	1613	21.911	158.009	1,061	87.64	20.73	0.00	0.94	0.00	0.00
94	2002	21.906	158.006	860	40.72	8.14	0.00	0.00	0.00	0.00
97	2318	21.802	157.998	1,028	48.66	16.54	0.97	0.00	0.00	0.00
98	16	21.757	157.999	889	44.99	14.62	0.00	0.00	0.00	0.00
105	2254	20.822	158.887	1,128	13.29	10.63	0.89	0.00	0.00	0.89
106	151	20.920	158.744	837	19.11	9.56	0.00	0.00	0.00	0.00
109	457	21.015	158.606	1,281	58.55	24.98	1.56	0.15	0.00	0.00
110	715	20.829	158.908	1,008	8.93	48.61	0.00	0.00	0.00	0.00
111	840	20.922	158.736	1,094	9.14	31.99	0.91	0.00	0.00	0.00
112	917	20.964	158.718	1,177	11.89	33.12	0.00	0.00	0.00	0.00
113	1106	21.016	158.581	917	13.09	28.35	0.00	0.00	0.00	0.00
114	1239	21.109	158.433	966	5.18	7.25	0.00	0.00	0.00	0.00
115	1416	21.202	158.266	1,071	4.67	39.22	0.00	0.00	0.00	0.00
116	1521	21.261	158.192	1,003	7.98	18.94	0.00	0.00	0.00	0.00
117	1554	21.266	158.151	1,930	7.25	21.76	0.00	0.00	0.00	0.00
118	2007	21.269	158.144	1,180	17.79	41.52	0.00	0.00	0.00	0.00
121	2253	21.261	158.192	1,404	34.18	0.71	0.71	0.00	0.00	0.00
122	2	21.206	158.262	1,025	43.91	14.64	0.00	0.00	0.00	0.00
124	139	21.208	158.269	868	46.08	10.37	0.00	0.00	0.00	0.00

Table 2.--Continued.

Sta. no.	Time of day	Lat. °N	Long. °W	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena hippurus</i>	<i>C. equiselis</i>	Flying fishes	Bill-fishes
125	324	21.110	158.427	673	37.16	8.92	0.00	0.00	0.00	0.00
127	742	21.412	158.552	1,067	14.06	16.87	0.00	0.00	0.00	0.00
128	912	21.415	158.368	1,283	7.79	10.13	0.00	0.00	0.00	0.00
129	1005	21.415	158.274	1,380	14.50	25.37	0.00	0.00	0.00	0.00
130	1041	21.414	158.233	1,325	7.55	6.04	0.00	0.00	0.00	0.00
131	1201	21.501	158.281	1,203	20.79	33.26	0.83	0.00	0.00	0.00
132	1259	21.501	158.323	1,051	2.86	9.52	0.00	0.00	0.00	0.00
133	1727	21.500	158.405	1,039	14.44	16.37	0.00	0.00	0.00	0.00
134	1956	21.410	158.553	754	39.79	7.96	0.00	0.00	0.00	0.00
136	2132	21.401	158.548	926	21.60	12.96	0.00	0.00	0.00	0.00
137	2308	21.402	158.371	1,109	18.04	4.51	0.00	0.00	0.00	0.00
140	151	21.420	158.272	1,117	35.80	2.69	0.00	0.00	0.00	0.00
141	238	21.414	158.244	1,166	25.72	67.74	0.00	0.00	0.00	0.00
143	749	21.602	158.329	981	14.27	44.83	0.00	0.00	0.00	0.00
144	848	21.615	158.373	1,167	12.85	69.41	0.00	0.00	0.00	0.00
145	1000	21.639	158.461	1,141	1.75	19.28	0.00	0.00	0.00	0.00
146	1144	21.704	158.634	986	2.03	20.28	0.00	0.00	0.00	0.00
147	1321	21.761	158.805	967	5.17	30.00	0.00	0.00	0.00	0.00
148	1623	21.500	158.595	964	20.75	53.95	0.00	0.00	0.00	0.00
149	2000	21.763	158.828	632	33.22	33.22	0.00	0.00	0.00	0.00
154	102	21.710	158.630	891	33.67	8.98	0.00	0.00	0.00	0.00
155	241	21.641	158.470	955	13.62	7.33	0.00	0.00	0.00	0.00
158	806	21.416	158.902	1,222	16.36	39.27	0.00	0.00	0.00	0.00
159	948	21.416	158.734	1,205	12.44	29.04	0.83	0.00	0.00	0.00
160	1022	21.413	158.734	1,124	4.45	35.58	0.00	0.00	0.00	0.89
161	1213	21.415	158.545	1,170	5.13	23.94	0.00	0.00	0.00	0.85
162	2005	21.604	158.329	1,011	49.47	38.58	0.99	0.00	0.00	0.00
165	2241	21.623	158.373	1,028	34.04	5.83	0.00	0.00	0.00	0.00
166	152	21.415	158.729	1,165	34.34	6.87	0.86	0.00	0.00	0.00
168	330	21.424	158.735	1,115	53.81	6.28	0.00	0.00	0.00	0.00
169	758	21.111	158.430	1,171	29.89	36.72	0.00	0.00	0.00	0.00
170	939	21.013	158.581	1,349	3.71	10.38	0.00	0.00	0.00	0.00
171	1128	20.920	158.734	1,139	7.02	23.71	0.00	0.00	0.00	0.00
172	1953	20.922	158.735	1,231	56.88	6.50	0.00	0.00	0.00	0.00
173	2133	21.010	158.586	700	85.71	5.71	0.00	0.00	0.00	0.00
174	2313	21.108	158.427	1,098	41.00	9.11	1.82	0.91	0.00	0.00

Isaac-Kidd Midwater

61	2207	21.924	156.982	3,098	12.91	5.16	0.00	0.00	0.00	0.00
63	117	21.828	157.176	3,558	17.43	5.06	0.00	0.00	0.00	0.00
65	349	21.730	157.326	2,080	28.84	3.85	0.00	0.00	0.00	0.00

Table 2.--Continued.

Sta. no.	Time of day	Lat. °N	Long. °W	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena</i> <i>hippurus</i>	<i>C.</i> <i>equisetis</i>	Flying fishes	Bill- fishes
75	2118	21.664	157.466	257	389.26	23.36	0.00	0.00	0.00	0.00
77	2350	21.555	157.626	555	72.06	27.02	0.00	0.00	0.00	0.00
78	111	21.495	157.710	455	24.18	6.59	0.00	0.00	0.00	0.00
81	338	21.482	157.749	--	--	--	0.00	0.00	0.00	0.00
82	2013	21.676	157.885	683	7.32	5.85	0.00	0.00	0.00	0.00
83	2106	21.672	157.885	1,512	56.22	81.35	0.00	0.00	0.00	0.00
85	2334	21.746	157.763	549	437.32	111.15	0.00	0.00	0.00	0.00
86	28	21.742	157.768	1,350	109.66	17.04	0.74	0.00	1.48	0.00
88	307	21.827	157.606	774	50.42	1.29	0.00	0.00	0.00	0.00
89	353	21.856	157.620	6,891	10.16	9.87	0.00	0.00	0.00	0.00
95	2050	21.905	157.998	681	139.48	45.51	0.00	0.00	0.00	0.00
96	2223	21.798	158.005	610	98.41	47.56	3.28	1.64	0.00	0.00
99	104	21.751	158.000	1,174	38.33	72.41	0.00	0.00	0.00	0.00
104	2151	20.826	158.900	1,348	66.79	17.81	0.00	0.00	0.00	0.74
108	417	21.015	158.600	322	248.45	236.02	3.11	6.21	0.00	0.00
120	2201	21.250	158.199	1,299	107.76	20.01	0.00	0.00	0.00	0.00
123	47	21.204	158.272	483	289.86	84.89	0.00	0.00	0.00	0.00
126	407	21.102	158.428	529	147.59	98.39	0.00	1.89	0.00	0.00
135	2041	21.411	158.567	6,892	13.35	1.89	0.00	0.00	0.00	0.00
138	2357	21.414	158.361	1,480	66.90	16.22	0.00	0.00	0.00	0.00
142	331	21.422	158.230	1,123	75.70	50.77	0.00	0.00	0.00	0.00
150	2059	21.757	158.839	6,074	11.52	6.59	0.00	0.00	0.00	0.00
151	2143	21.773	158.822	343	81.63	34.99	0.00	0.00	0.00	0.00
152	2335	21.704	158.650	336	252.98	26.79	0.00	0.00	0.00	0.00
153	18	21.705	158.636	911	184.33	13.17	0.00	0.00	0.00	0.00
156	331	21.645	158.482	6,976	11.47	2.58	0.00	0.00	0.00	0.00
157	417	21.637	158.485	6,707	1.49	1.19	0.00	0.00	0.00	0.00
163	2054	21.601	158.324	779	46.21	97.55	0.00	0.00	0.00	0.00
164	2152	21.618	158.374	2,102	32.35	20.93	0.00	0.48	0.00	0.00

Table 3.-Catches during cruise TC-88-06 off leeward and windward Oahu and Kailua-Kona, Hawaii in September 1988.

Sta. no.	Time of day	Lat. °N	Long. °W	Water strained m ³	Plankton volume ml/1,000 m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena hippurus</i>	<i>C. equiselis</i>	Flying fishes	Billfishes
Manta Net										
40	1544	21.049	158.845	--	(5) ^a	(18)	(0)	(0)	(1)	(1)
42	1947	20.820	158.891	530	28.28	16.97	0.00	0.00	0.00	0.00
45	2309	20.919	158.737	748	13.36	10.69	0.00	0.00	0.00	2.67
47	153	20.993	158.587	546	27.48	21.98	0.00	0.00	0.00	0.00
49	427	21.121	158.457	967	41.37	47.58	0.00	0.00	0.00	1.03
51	755	21.275	158.152	1,091	16.51	39.43	0.00	0.92	0.92	4.58
52	836	21.255	158.192	1,065	16.91	22.54	0.00	0.94	0.94	2.82
53	924	21.206	158.267	987	10.13	17.22	1.01	1.01	0.00	0.00
54	1046	21.109	158.430	982	14.26	15.28	0.00	0.00	0.00	1.02
55	1208	21.020	158.580	955	9.43	11.52	0.00	0.00	1.05	0.00
56	1328	20.923	158.736	953	5.25	8.39	0.00	0.00	1.05	0.00
57	1450	20.828	158.891	927	6.47	20.49	0.00	1.08	1.08	2.16
59	107	21.201	158.265	626	31.92	12.77	0.00	1.60	0.00	0.00
61	257	21.255	158.190	994	28.16	33.18	1.01	2.01	0.00	0.00
62	408	21.277	158.151	703	69.68	27.02	0.00	5.69	0.00	0.00
64	1456	21.736	157.319	563	5.33	19.53	0.00	0.00	0.00	0.00
65	1628	21.833	157.161	732	13.67	49.21	0.00	1.37	0.00	0.00
66	1800	21.926	157.003	623	33.69	59.37	0.00	0.00	0.00	0.00
69	30	21.925	157.002	609	73.88	24.63	0.00	0.00	0.00	0.00
71	259	21.833	157.159	732	34.17	45.11	0.00	0.00	0.00	0.00
72	430	21.737	157.319	809	37.09	42.03	0.00	0.00	0.00	0.00
74	1308	21.650	157.472	1,041	19.21	36.51	0.00	0.00	0.00	0.00
75	1430	21.539	157.623	1,068	4.68	0.00	0.00	0.00	0.00	0.00
76	1514	21.512	157.695	1,080	18.51	99.98	0.00	0.00	0.00	0.00
77	1555	21.482	157.742	679	11.79	7.37	0.00	0.00	0.00	0.00
79	2038	21.641	157.484	851	35.24	10.57	0.00	0.00	0.00	1.17
82	21	21.537	157.628	619	40.36	50.05	0.00	0.00	0.00	0.00
84	221	21.506	157.710	719	26.42	37.54	0.00	0.00	0.00	0.00
85	313	21.478	157.755	715	62.90	78.28	0.00	0.00	0.00	0.00
88	2029	19.302	157.166	1,035	28.98	8.69	0.97	1.93	0.00	0.00
90	2218	19.317	157.018	996	58.21	10.04	1.00	4.01	0.00	1.00
92	24	19.337	156.835	764	89.03	36.66	2.62	5.24	0.00	0.00
94	337	19.362	156.651	935	52.40	6.42	1.07	4.28	0.00	0.00
95	921	19.364	156.647	759	17.14	31.64	0.00	0.00	1.32	0.00
97	1217	19.334	156.833	907	99.18	63.91	2.20	2.20	0.00	0.00
98	1341	19.318	157.013	1,796	38.98	10.02	0.00	0.00	0.00	0.00
99	1450	19.301	157.160	907	63.96	40.80	0.00	0.00	0.00	0.00
101	2128	19.399	156.472	717	46.04	5.58	0.00	5.58	0.00	0.00
103	2328	19.428	156.285	915	68.84	5.46	0.00	3.28	0.00	0.00
105	211	19.463	156.127	1,037	86.79	10.61	0.96	7.71	0.00	0.96
107	353	19.469	156.012	928	134.68	24.78	0.00	1.08	0.00	2.15
108	441	19.472	155.974	982	103.91	21.39	0.00	4.07	0.00	0.00
111	1302	19.398	156.472	1,007	20.86	0.99	0.00	0.00	0.00	0.00
112	1429	19.433	156.293	1,022	29.37	16.64	0.00	0.00	0.00	0.00
113	1558	19.454	156.111	929	112.98	18.29	1.08	2.15	0.00	0.00

Table 3.--Continued.

Sta. no.	Time of day	Lat. °N	Long. °W	Water strained m ³	Plankton volume ml/1000m ³	Number/1,000 m ³				
						Fish larvae	<i>Coryphaena hippurus</i>	<i>C. equiselus</i>	Flying fishes	Bill-fishes
114	1648	19.470	156.023	917	34.92	25.10	0.00	1.09	0.00	0.00
115	1728	19.475	155.985	970	121.65	63.92	0.00	2.06	0.00	0.00
Isaac-Kidd midwater trawl										
43	2042	20.828	158.891	10,751	6.0	3.2	0.09	0.00	0.00	0.00
44	2214	20.909	158.749	11,180	4.9	10.3	0.00	0.00	0.00	0.09
46	0041	21.010	158.593	12,162	4.9	11.2	0.00	0.00	0.00	0.00
48	0327	21.098	158.444	12,656	6.3	9.6	0.00	0.00	0.00	0.00
58	0012	21.220	158.233	13,437	6.0	3.6	0.08	0.08	0.00	0.07
60	0202	21.243	158.218	13,193	9.1	4.3	0.00	0.00	0.00	0.00
63	0447	21.242	158.120	13,376	11.1	7.4	0.00	0.00	0.00	0.00
68	2336	21.950	157.979	12,934	5.0	7.9	0.00	0.00	0.00	0.00
70	0200	21.845	157.139	13,043	5.3	12.1	0.08	0.08	0.00	0.00
73	0517	21.731	157.292	13,133	3.0	7.5	0.00	0.00	0.00	0.00
78	1947	21.652	157.467	13,912	6.7	5.0	0.00	0.00	0.00	0.00
81	2325	21.546	157.607	12,020	10.2	14.4	0.00	0.00	0.00	0.00
83	0123	21.524	157.690	12,389	7.2	6.0	0.00	0.15	0.00	0.00
86	0353	21.480	157.747	14,602	6.8	15.5	0.00	0.00	0.00	0.00
87	1934	19.309	157.161	12,092	10.2	6.2	0.00	0.00	0.00	0.00
89	2132	19.309	157.038	12,058	8.7	10.6	0.00	0.00	0.00	0.00
91	2334	19.330	156.852	12,681	7.9	5.7	0.00	0.00	0.00	0.00
93	0210	19.352	156.664	13,389	9.0	11.4	0.00	0.00	0.00	0.00
100	2042	19.394	156.493	13,034	12.3	8.4	0.00	0.00	0.00	0.00
102	2249	19.424	156.298	13,372	11.2	6.0	0.00	0.00	0.00	0.00
104	0105	19.468	156.129	12,651	9.5	10.3	0.00	0.00	0.00	0.00
106	0308	19.460	156.048	13,810	8.7	7.7	0.00	0.00	0.00	0.00
109	0510	19.459	155.952	12,863	7.8	8.4	0.00	0.00	0.00	0.00

^aactual amount or number caught.

Table 4.--Correlation among components of day and night plankton samples and some physical environmental factors (N = 54).

	Zooplankton volume		Fish larvae		Coryphaena hippurus		C. equisetis		Billfishes		Flying fishes		Distance from shore	Surface temperature	Surface salinity
	night	day	night	day	night	day	night	day	day	night	day	day			
Zooplankton volume night	1.0000 ^a	0.3410	0.0759	0.2369	0.0838	0.0333	0.4076	0.4324	-0.1412	0.4447	-0.0027	-0.1198	-0.1084	-0.0806	
	0.0000 ^b	0.0116	0.5852	0.0845	0.5468	0.8109	0.0022	0.0011	0.3086	0.0008	0.9843	0.3884	0.4353	0.5621	
Zooplankton volume day	0.3410	1.0000	-0.2994	0.3416	0.3673	0.1677	0.3695	0.5996	-0.1843	-0.0198	-0.1268	-0.1118	-0.1084	-0.0806	
	0.0116	0.0000	0.0278	0.0115	0.0063	0.2256	0.0060	0.0000	0.1821	0.8873	0.3611	0.4208	0.0534	0.0345	
Fish larvae night	0.0759	-0.2994	1.0000	0.0043	-0.1199	0.1448	-0.1368	-0.0138	-0.0815	0.0825	0.0213	-0.1867	-0.3680	-0.4027	
	0.5852	0.0278	0.0000	0.9755	0.3876	0.2960	0.3240	0.9212	0.5580	0.5533	0.8787	0.1764	0.0062	0.0025	
Fish larvae day	0.2369	0.3416	1.0043	1.0000	0.2595	0.2311	0.1503	0.4052	0.1234	0.1857	0.0792	0.0998	-0.2700	-0.2990	
	0.0845	0.0115	0.9756	0.0000	0.0581	0.0927	0.2780	0.0024	0.3740	0.1789	0.5693	0.4729	0.0483	0.0281	
Coryphaena hippurus night	0.0838	0.3673	-0.1199	0.2595	1.0000	0.4860	0.3880	0.2208	0.1919	-0.0764	-0.0501	0.3219	0.1350	0.1166	
	0.5468	0.0063	0.3876	0.0581	0.0000	0.0002	0.0037	0.1085	0.1646	0.5831	0.7192	0.0176	0.3303	0.4010	
Coryphaena hippurus day	0.0333	0.1677	0.1448	0.2311	0.4877	1.0000	0.0681	0.2146	0.2892	-0.0378	-0.0886	0.2839	-0.1681	-0.2177	
	0.8109	0.2256	0.2960	0.0927	0.0002	0.0000	0.6247	0.1191	0.0339	0.7863	0.5241	0.0375	0.2244	0.1139	
Coryphaena equisetis night	0.4076	0.3694	-0.1368	0.1503	0.3880	0.0681	1.0000	0.4136	0.1259	-0.0263	0.2586	0.0775	-0.0785	-0.0855	
	0.0022	0.0060	0.3240	0.2781	0.0037	0.6248	0.0000	0.0019	0.3642	0.8505	0.0590	0.5775	0.5725	0.5389	
Coryphaena equisetis day	0.4324	0.5996	-0.0138	0.4052	0.2208	0.2146	0.4136	1.0000	0.0689	0.1663	0.2343	-0.0450	-0.2014	-0.1914	
	0.0011	0.0000	0.9212	0.0024	0.1085	0.1191	0.0019	0.0000	0.6206	0.2293	0.0882	0.7464	0.1442	0.1656	
Billfishes day	-0.1412	-0.1843	-0.0815	0.1234	0.1919	0.2892	0.1259	0.0689	1.0000	-0.0027	0.4717	0.2109	-0.4291	-0.4239	
	0.3086	0.1821	0.5580	0.3740	0.1646	0.0339	0.3642	0.6206	0.0000	0.9847	0.0003	0.1258	0.0012	0.0014	
Flying fishes night	0.4447	-0.0198	0.0825	0.1857	-0.0764	-0.0378	-0.0262	0.1663	-0.0027	1.0000	-0.0658	0.1095	-0.1317	-0.1193	
	0.0008	0.8873	0.5533	0.1789	0.5832	0.7863	0.8507	0.2293	0.9847	0.0000	0.6366	0.4304	0.3425	0.3902	

^aR.
^bProbability.

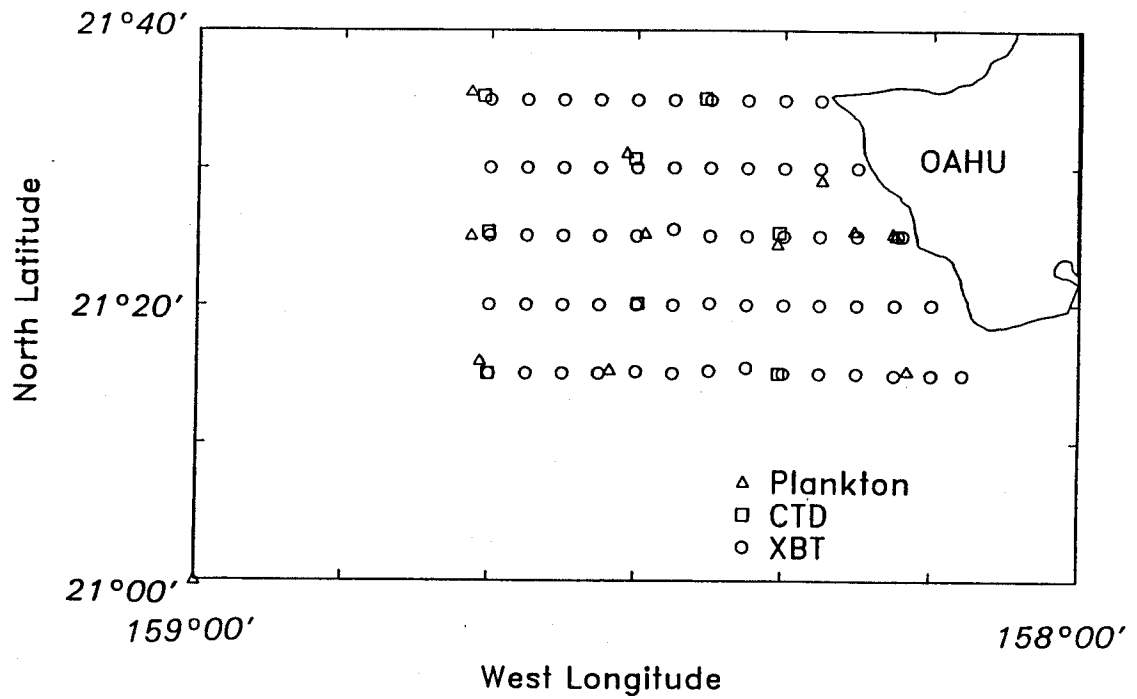


Figure 1.--Stations sampled off leeward Oahu during cruise TC-87-06 by the NOAA ship *Townsend Cromwell* in October 1987.

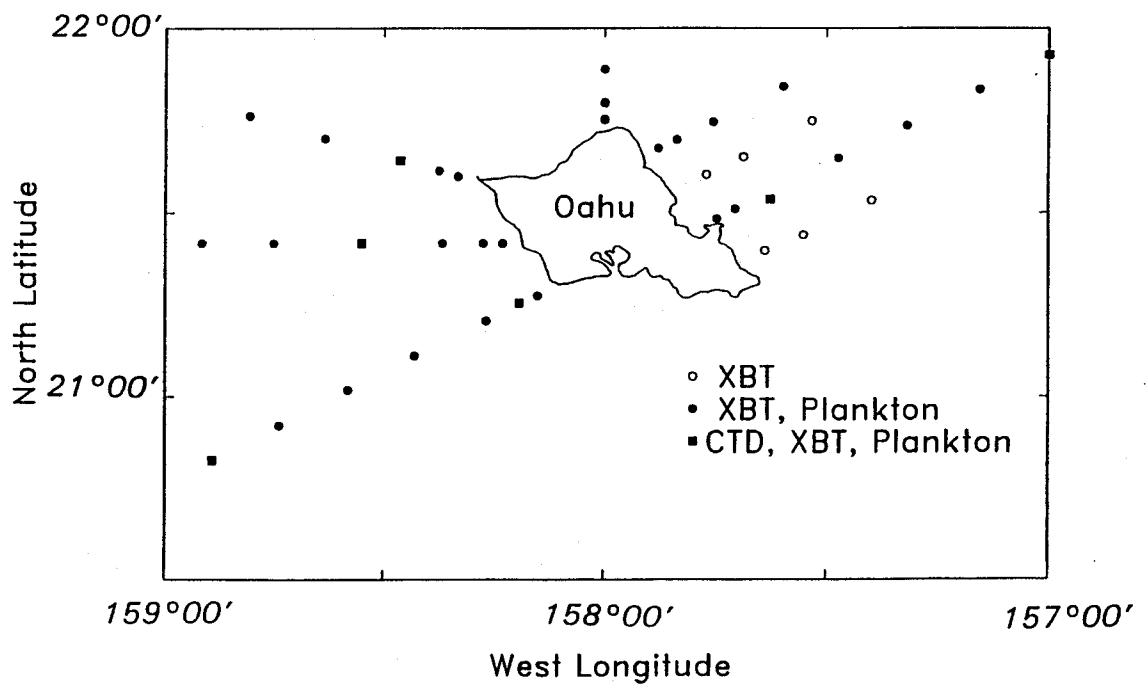


Figure 2.--Stations sampled off leeward and windward Oahu during cruise TC-88-03 Leg II by the NOAA ship *Townsend Cromwell* in April-May 1988.

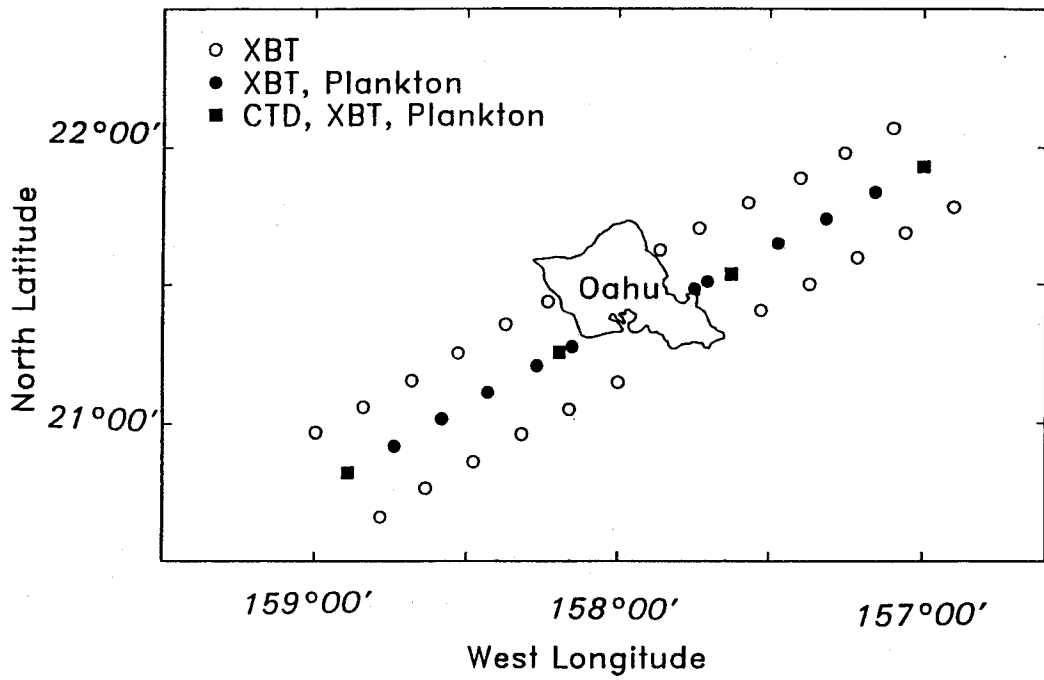


Figure 3.--Stations sample during cruise TC-88-06 Leg II by the NOAA ship *Townsend Cromwell* in September 1988: (A) off leeward and windward Oahu.

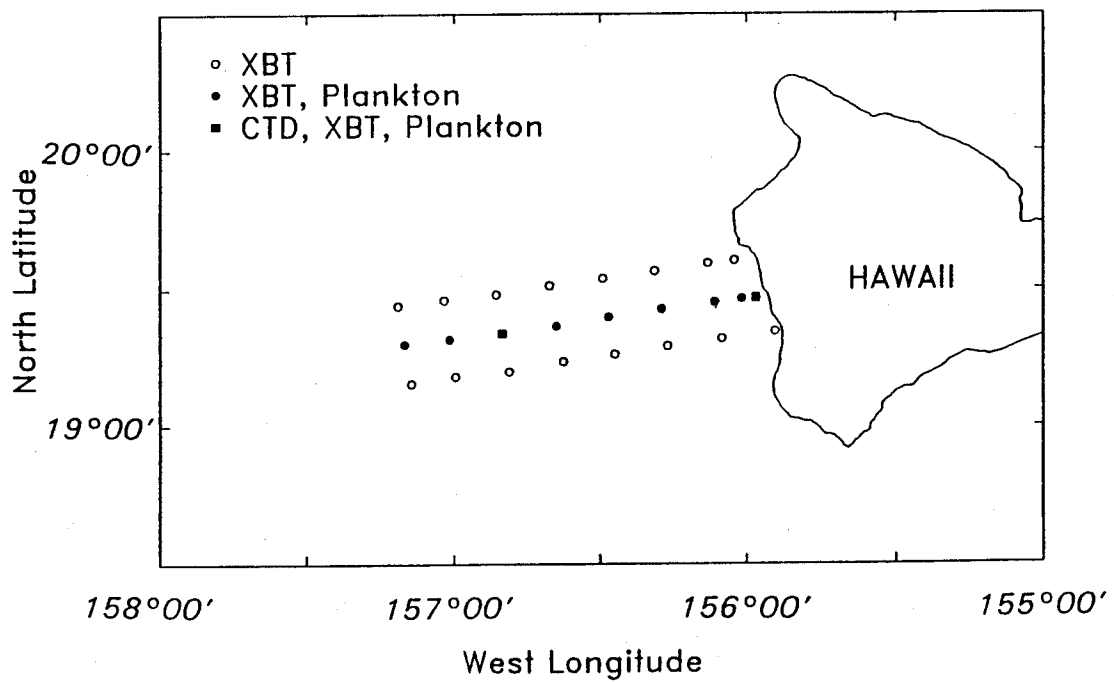


Figure 3.--Continued. (B) Kailua-Kona, Hawaii.

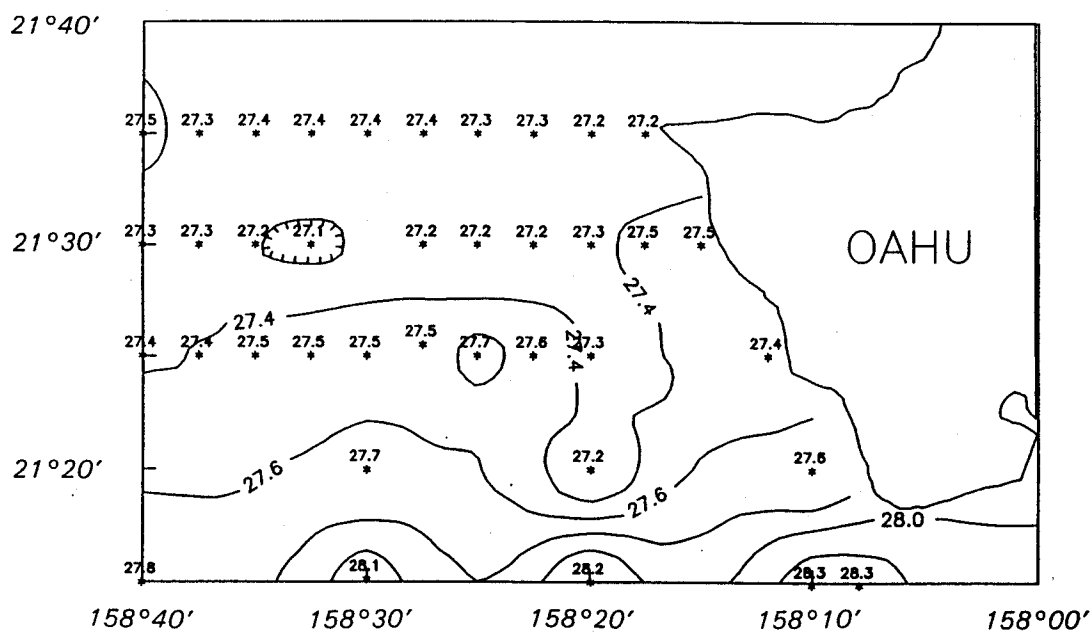


Figure 4.--Oceanographic data collected off leeward Oahu, 14-15 October 1987. (A) Surface temperature.

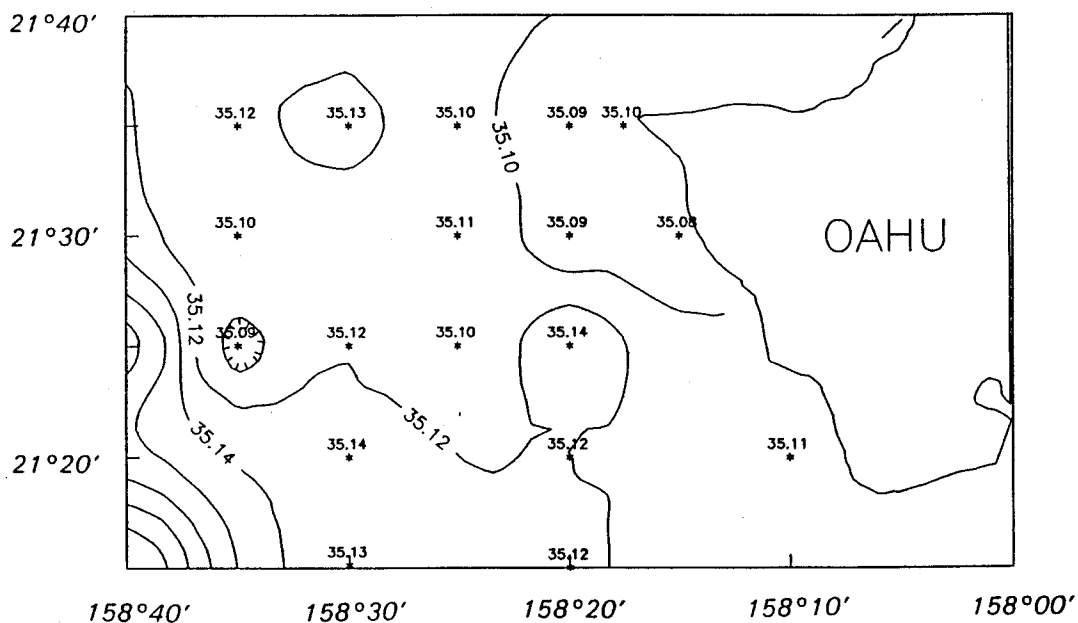


Figure 4.--Continued. (B) Surface salinity.

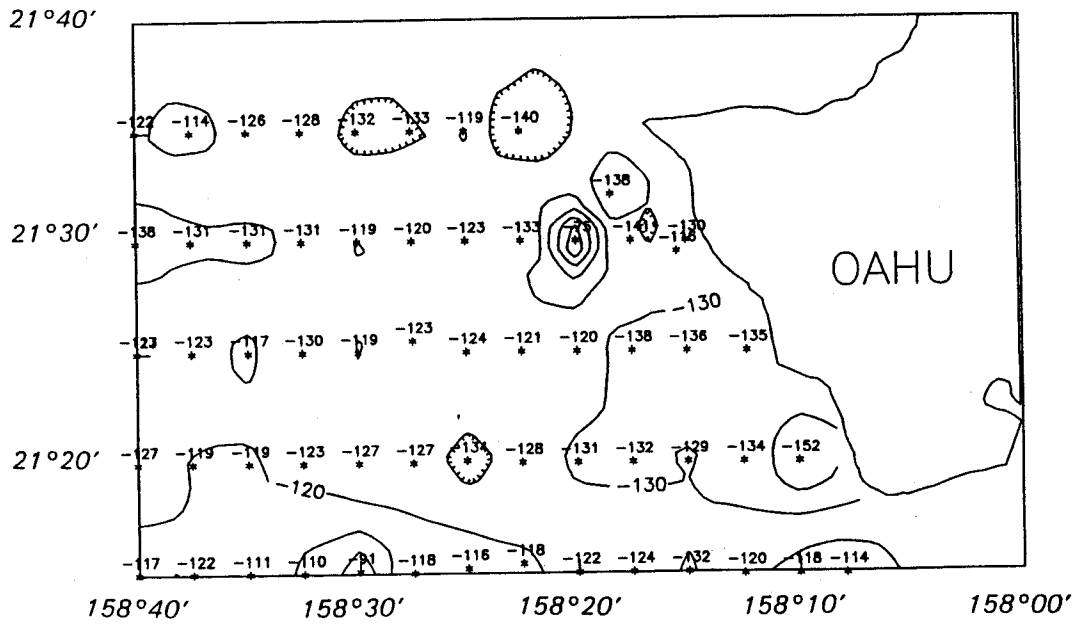


Figure 4.--Continued. (C) The 20°C isotherm depth.

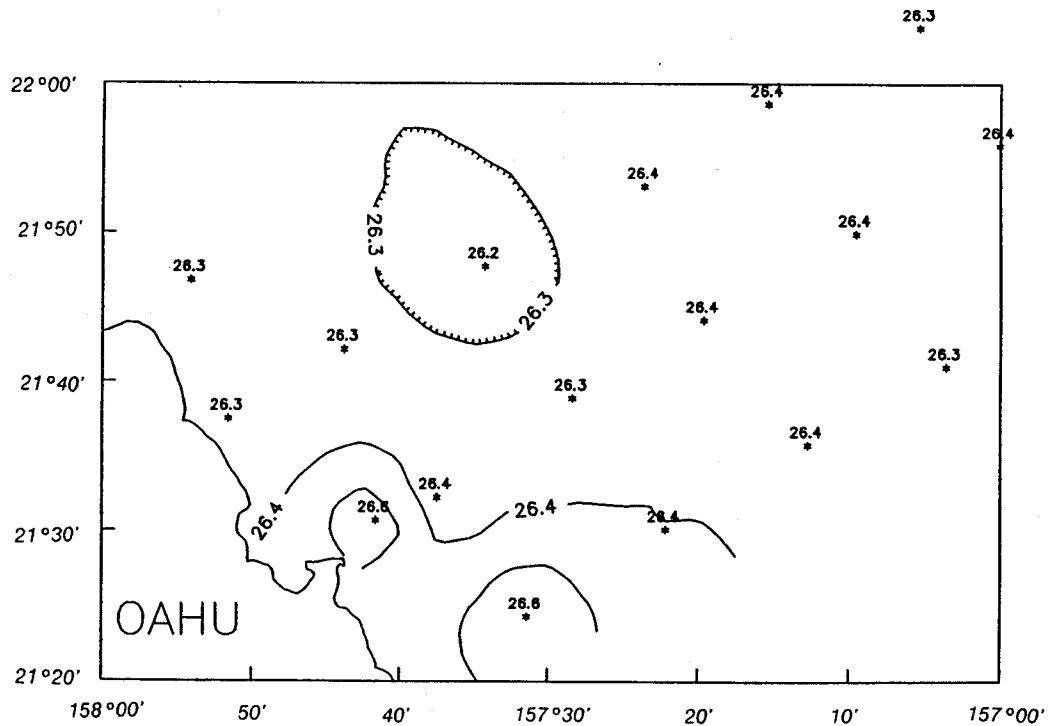


Figure 5.--Oceanographic data collected off windward Oahu, 23 April 1988. (A) Surface temperature.

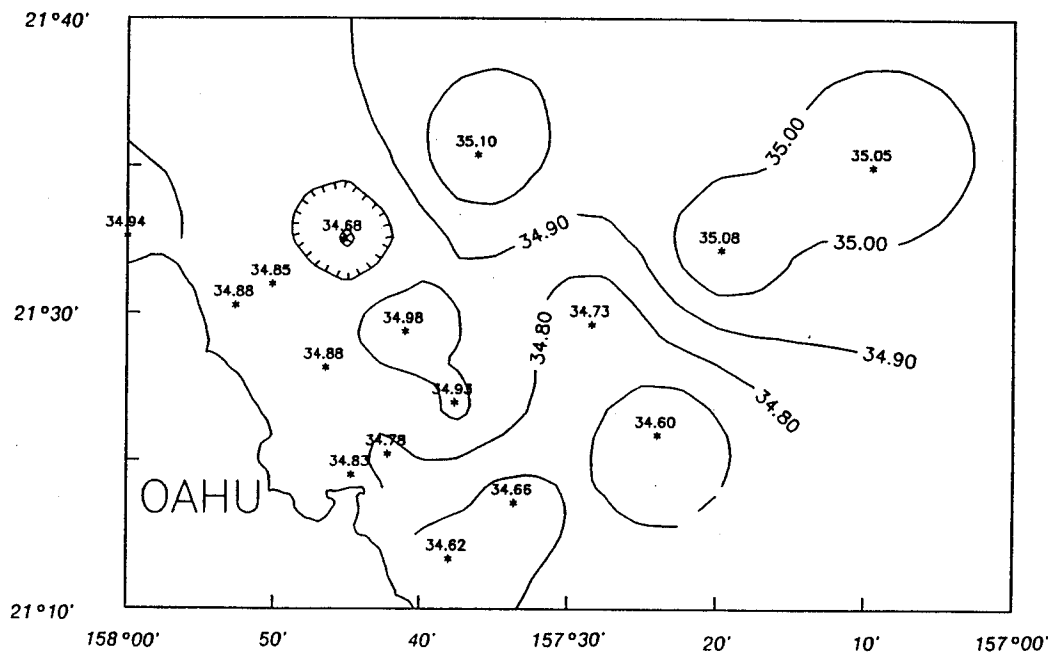


Figure 5.--Continued. (B) Surface salinity.

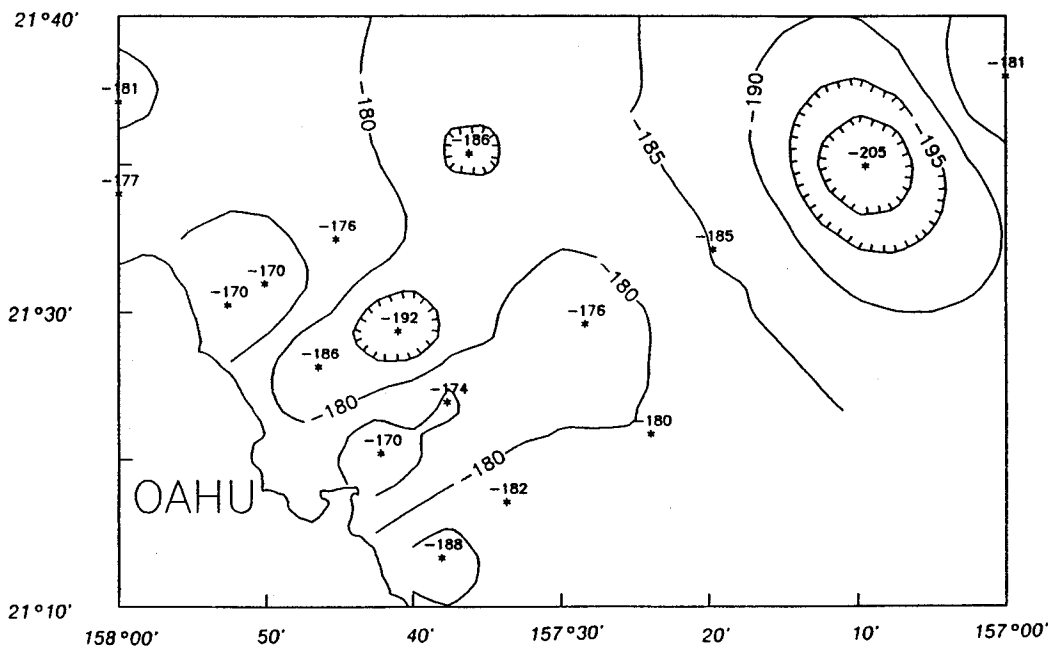


Figure 5.--Continued. (C) The 20°C isotherm depth.

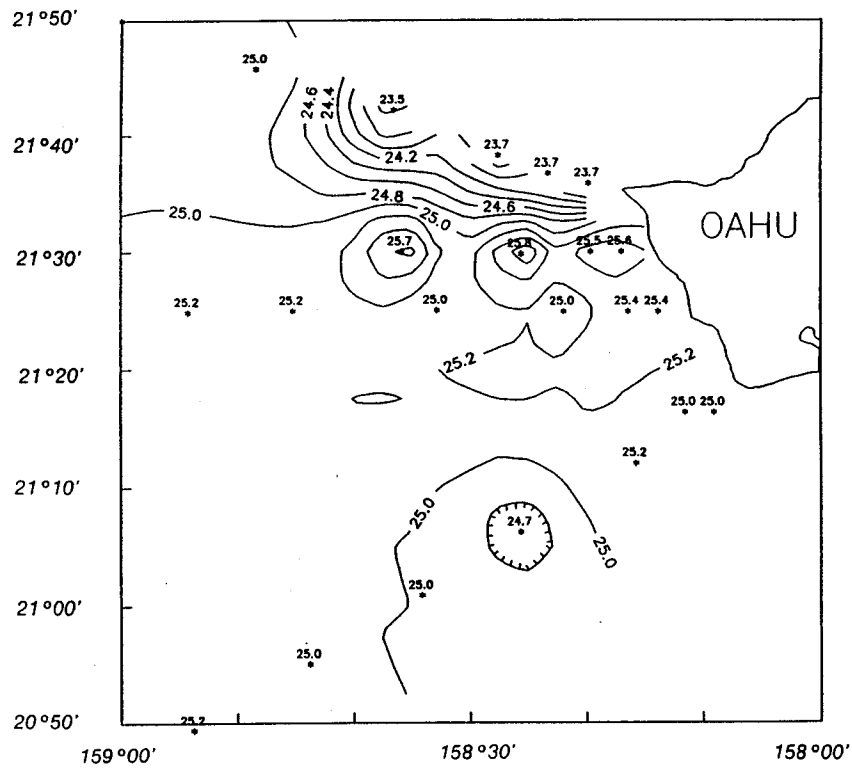


Figure 6A.--Oceanographic data collected off leeward Oahu, 27 April 1988. (A) Surface temperature.

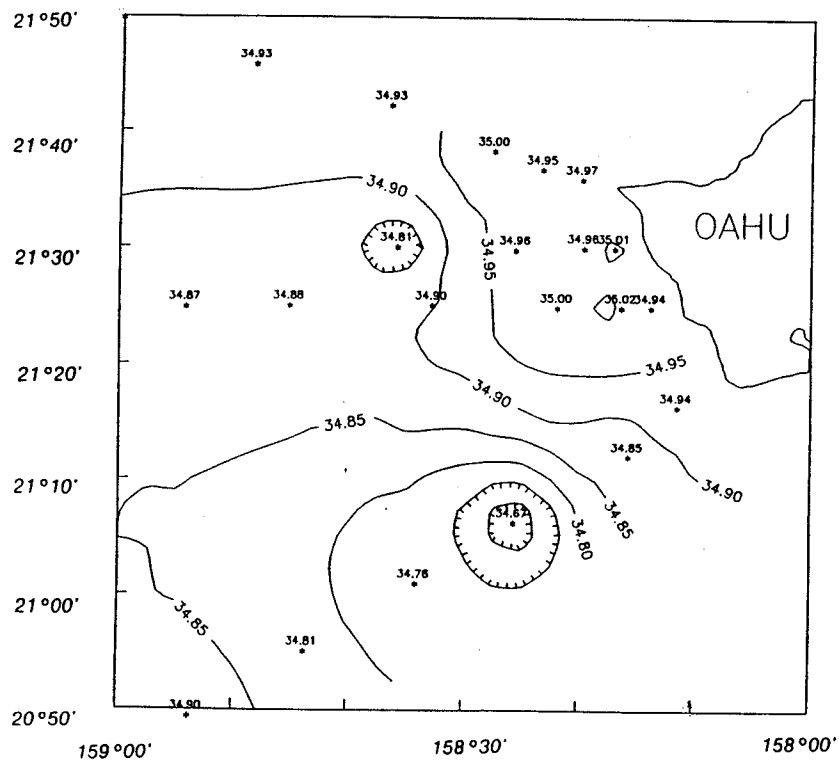


Figure 6.--Continued. (B) Surface salinity.

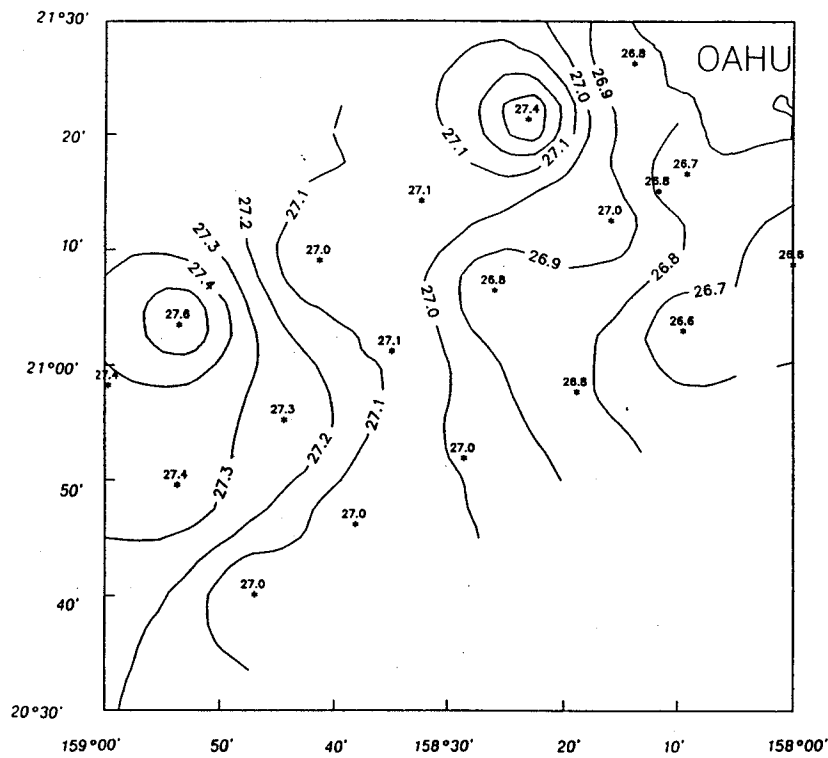


Figure 7.--Oceanographic data collected off leeward Oahu, 22-23 September 1988. (A) Surface temperature.

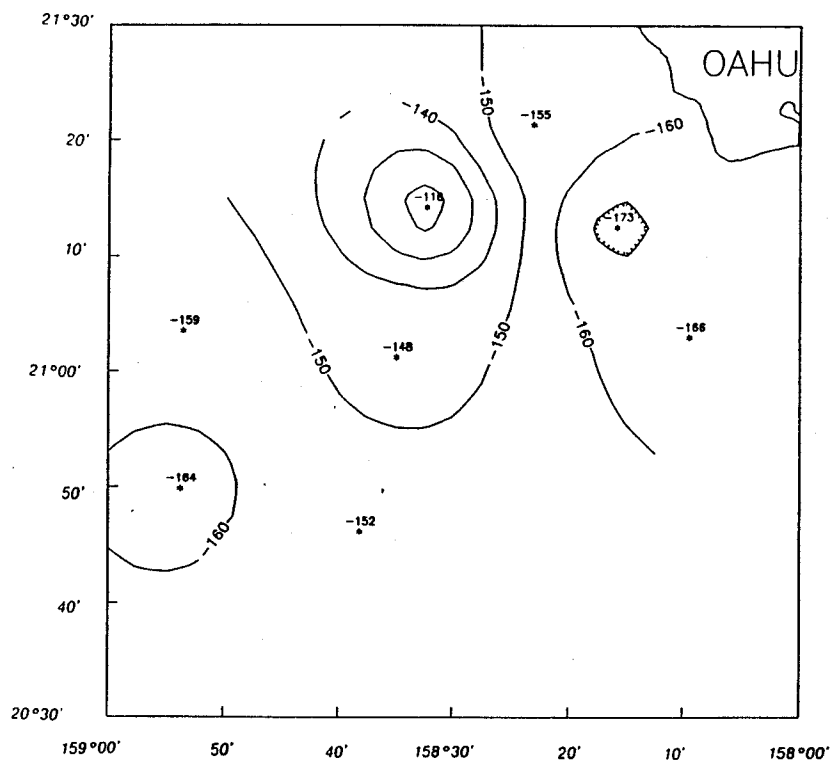


Figure 7.--Continued. (B) The 20°C isotherm depth.

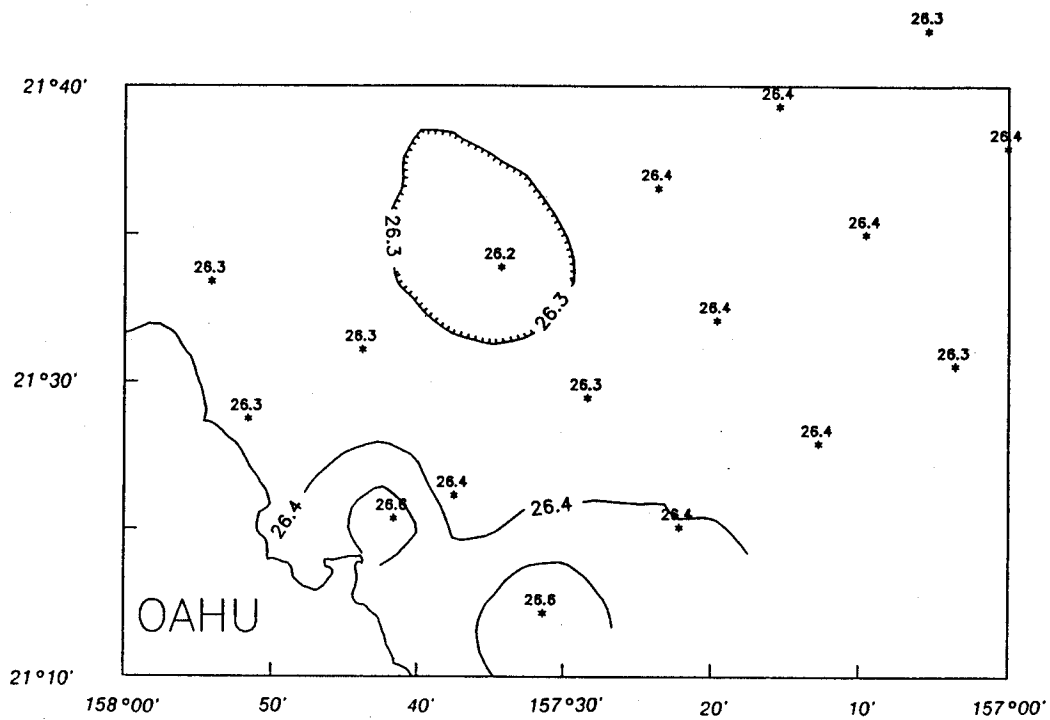


Figure 8.--Surface temperature off windward Oahu, 24-26 September 1988.

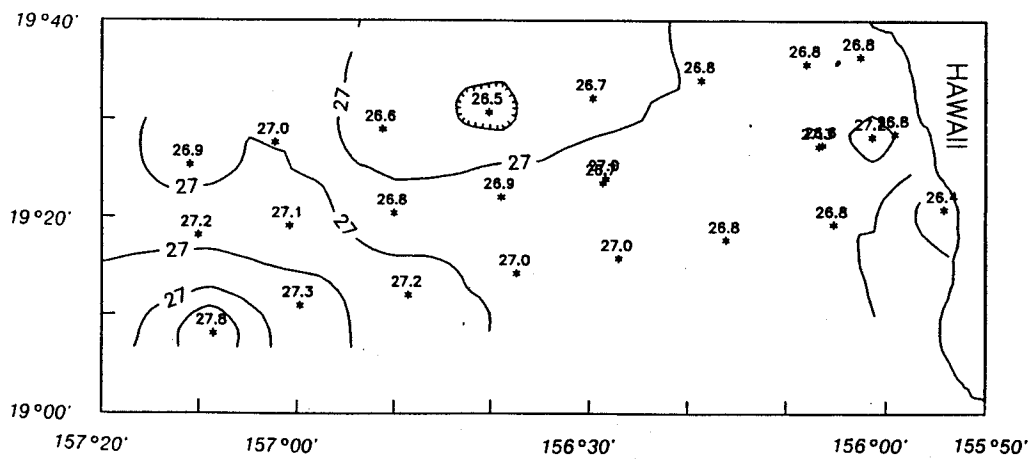


Figure 9.--Oceanographic data collected off Kailua-Kona, Hawaii, 26-28 September 1988. (A) Surface temperature.

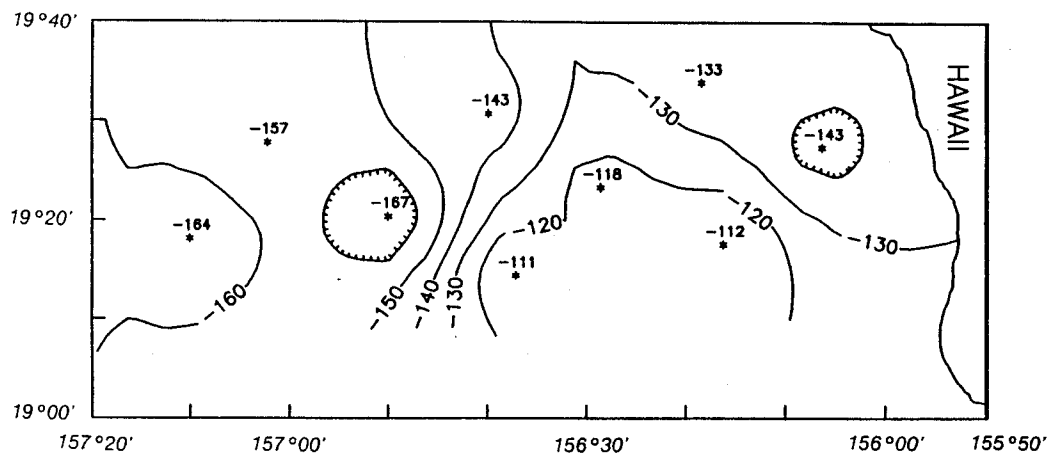


Figure 9.--Continued. (B) The 20°C isotherm depth.

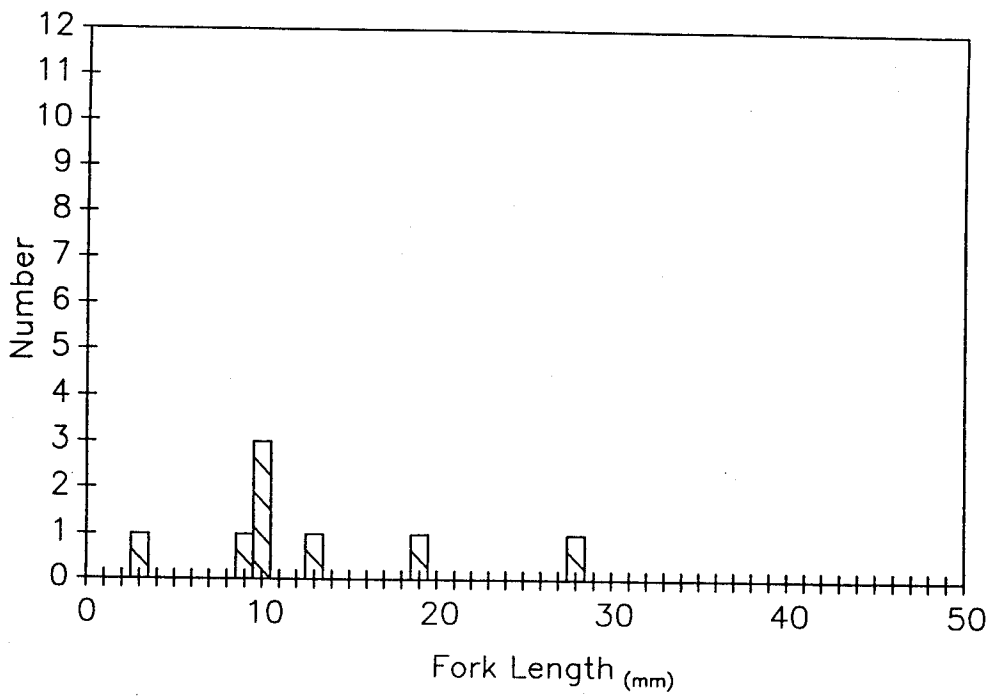


Figure 10.--Length-frequency distributions of *Coryphaena* sp. caught by several gear types: (A) Isaacs-Kidd midwater trawl and neuston trawl.

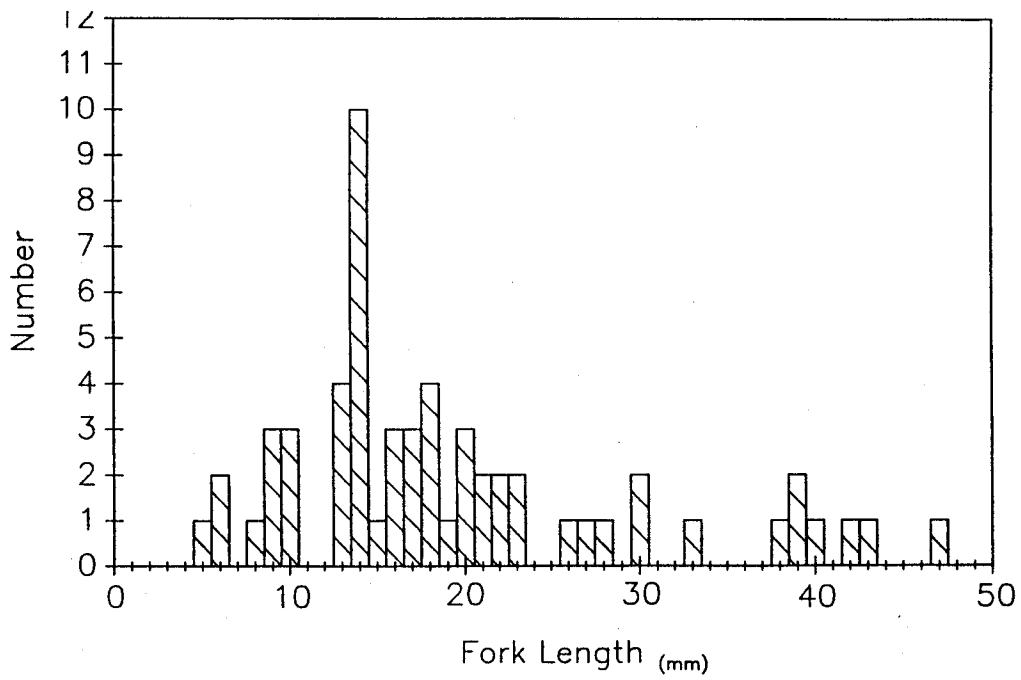


Figure 10.--Continued. (B) Manta.

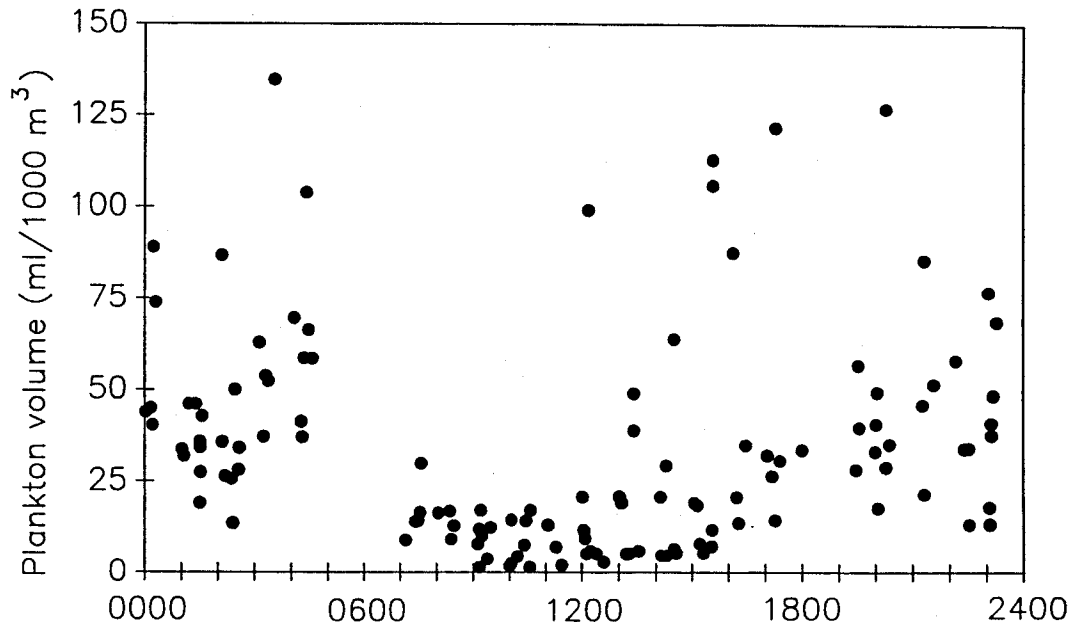


Figure 11.--Densities of zooplankton over 24 hours during cruises TC-88-03 and TC-88-06 by the NOAA ship *Townsend Cromwell*.

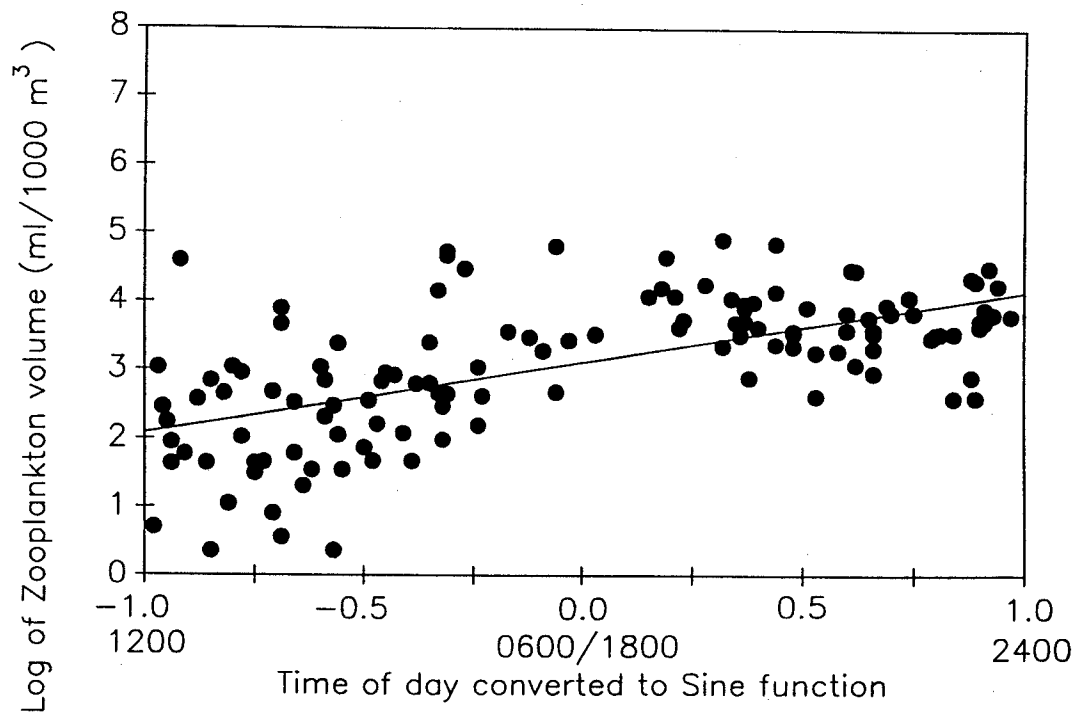


Figure 12.--Linear regression of the log of zooplankton volume on time which was converted to a sine function.

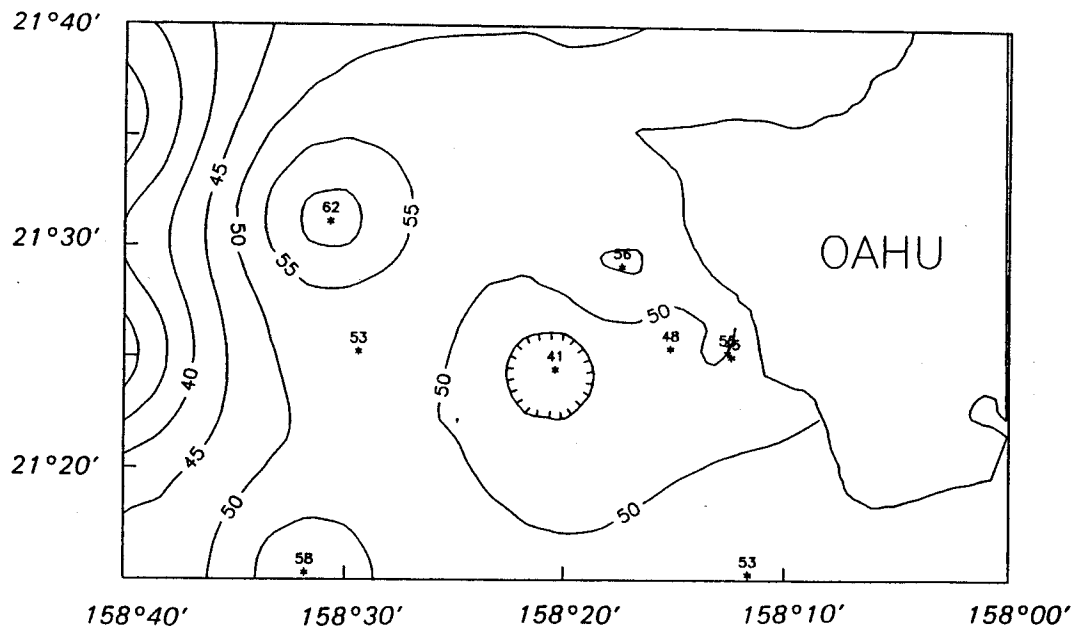


Figure 13.--Adjusted surface zooplankton densities off leeward Oahu, October 1987.

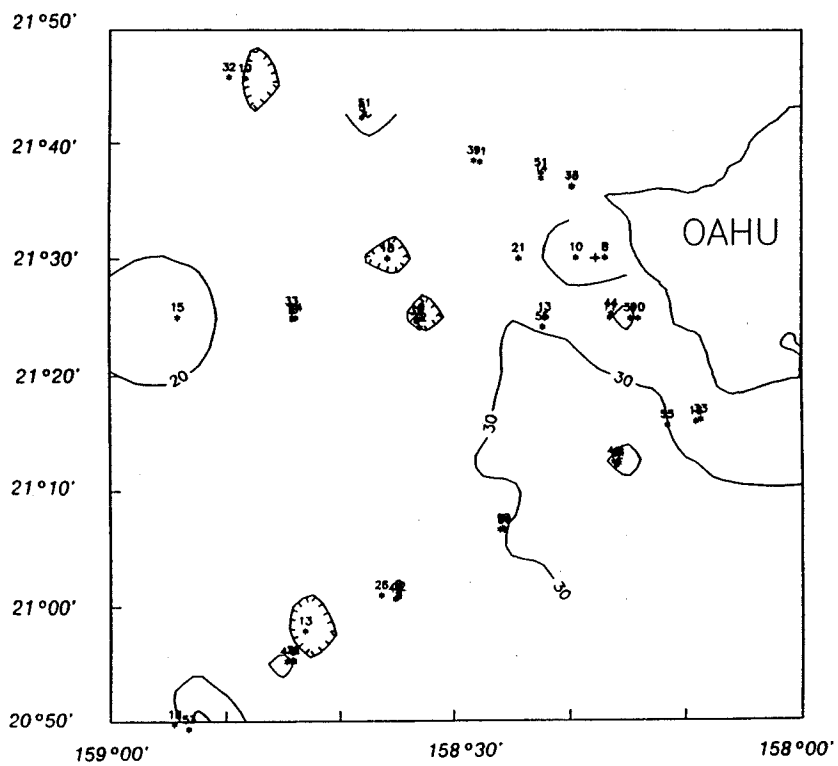


Figure 14A.--Adjusted surface zooplankton densities off leeward Oahu, April-May 1988.

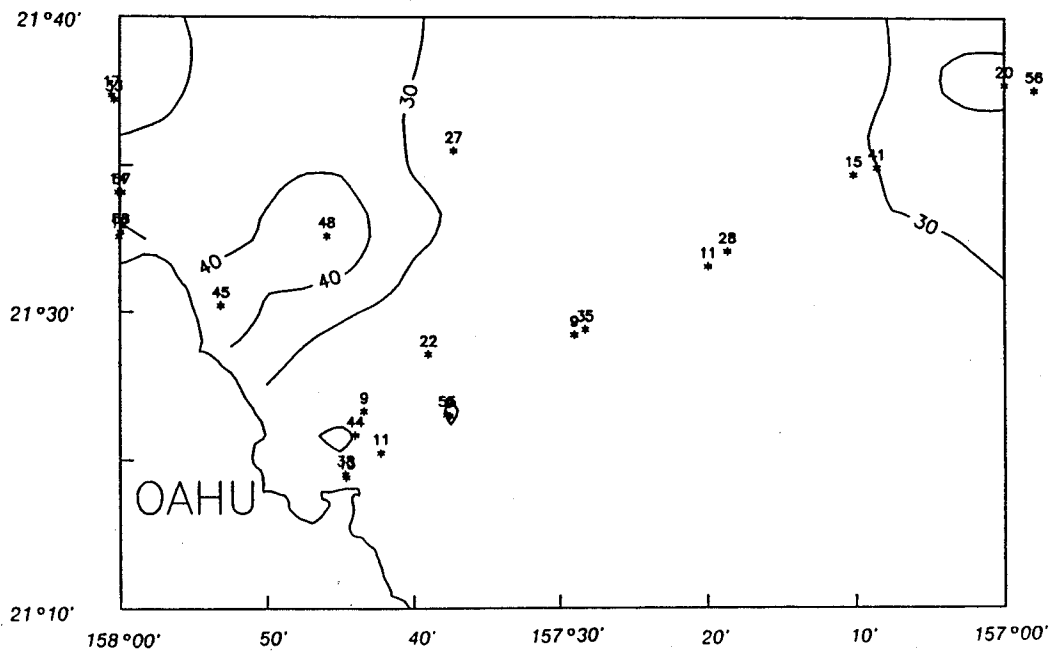


Figure 14B.--Adjusted surface zooplankton densities off windward Oahu, April 1988.

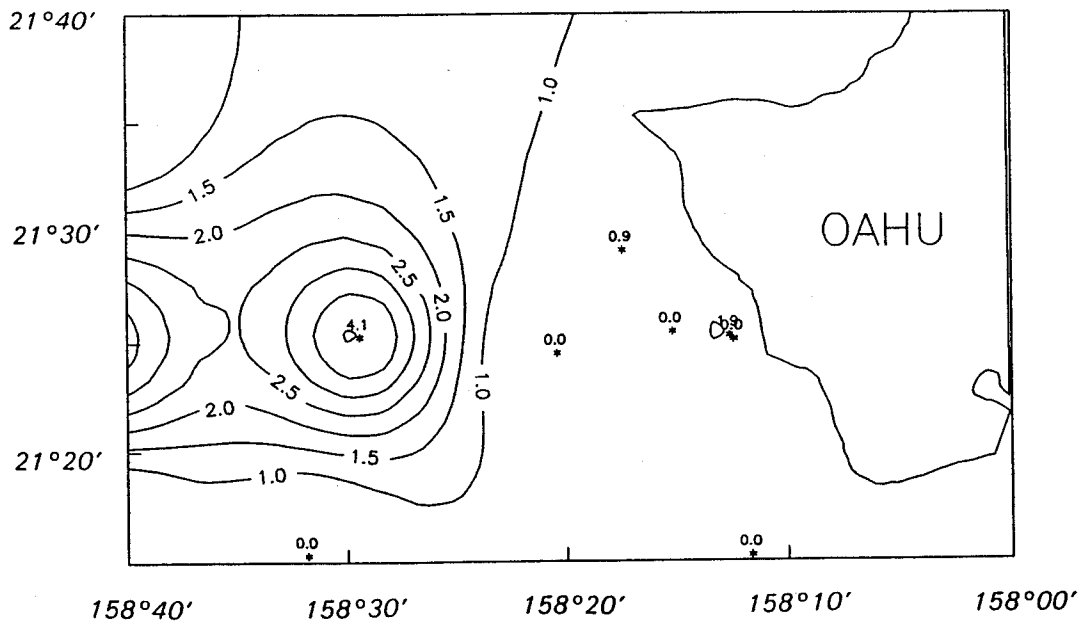


Figure 15.--Contours of densities of larvae and postlarval *Coryphaena equiselis* collected at the surface at night off leeward Oahu, October 1987.

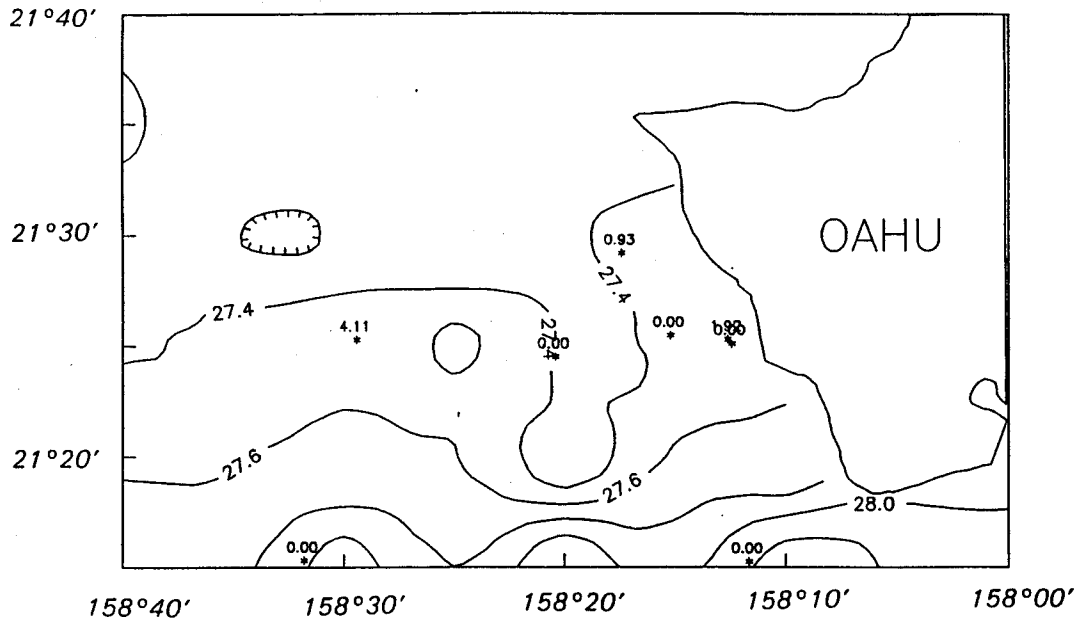


Figure 16.--Densities of larval and postlarval *Coryphaena equiselis* caught in samples posted on the following contours off leeward Oahu in October 1987: (A) Surface temperature contours.

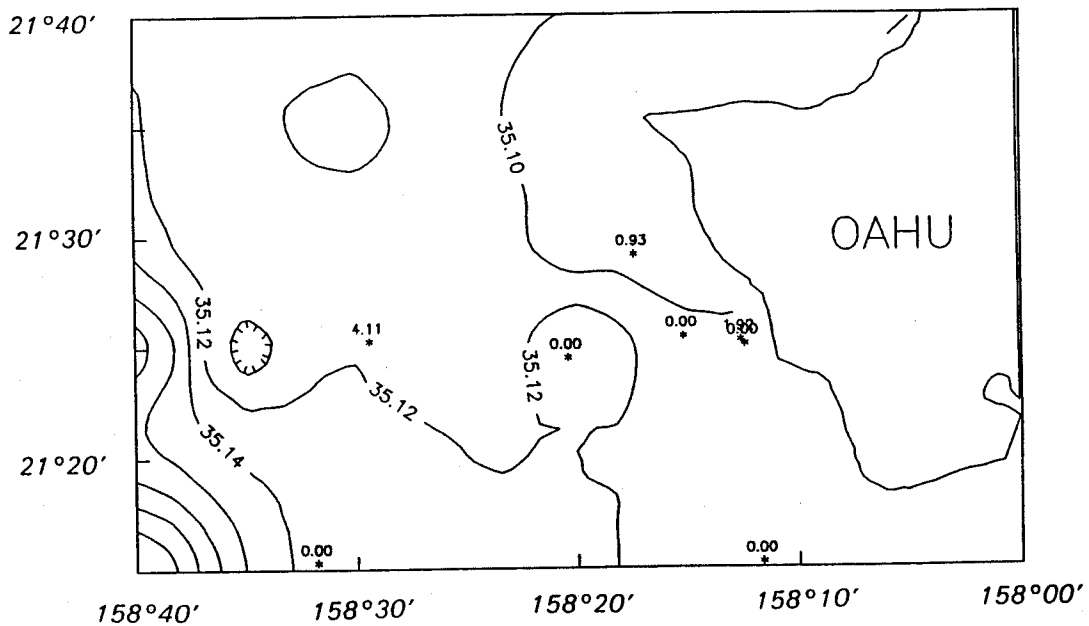


Figure 16.--Continued. (B) Surface salinity contours.

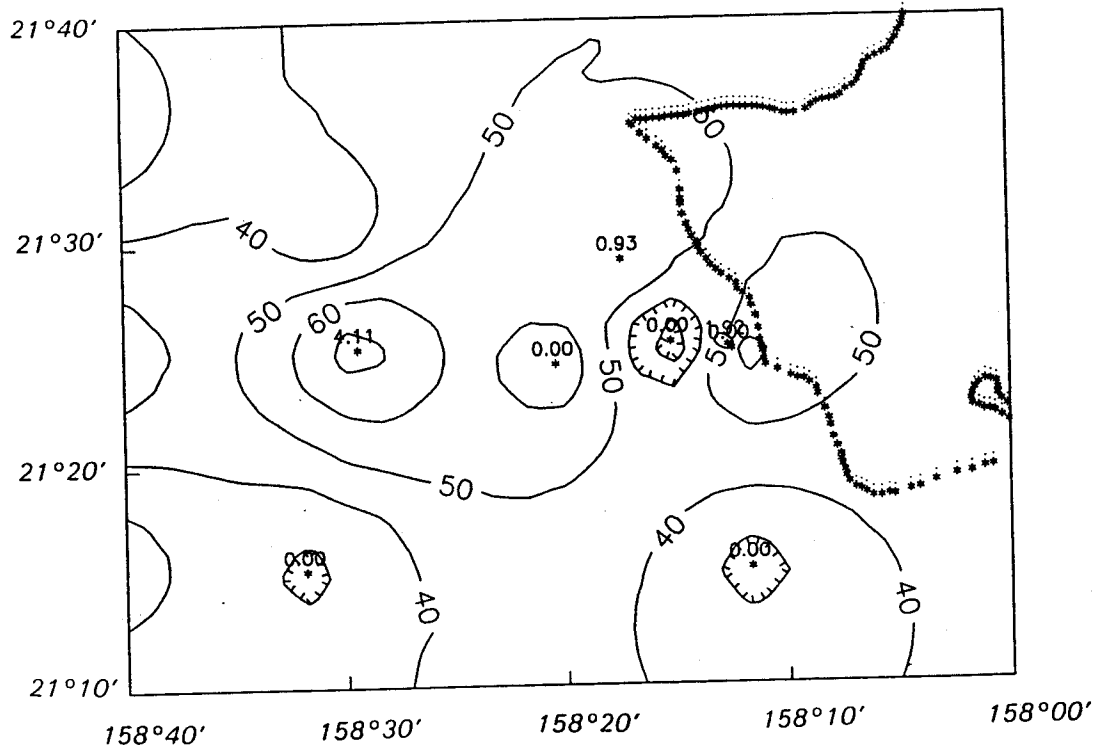


Figure 16.--Continued. (C) Contours of actual surface zooplankton densities.

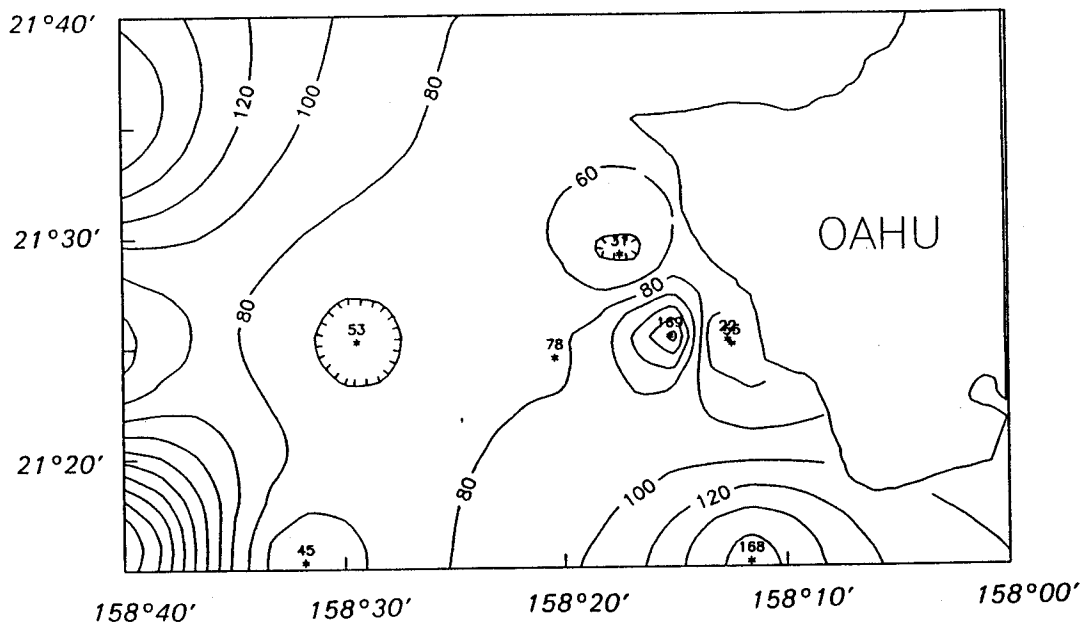


Figure 16.--Continued. (D) Contours of surface larval fish densities.

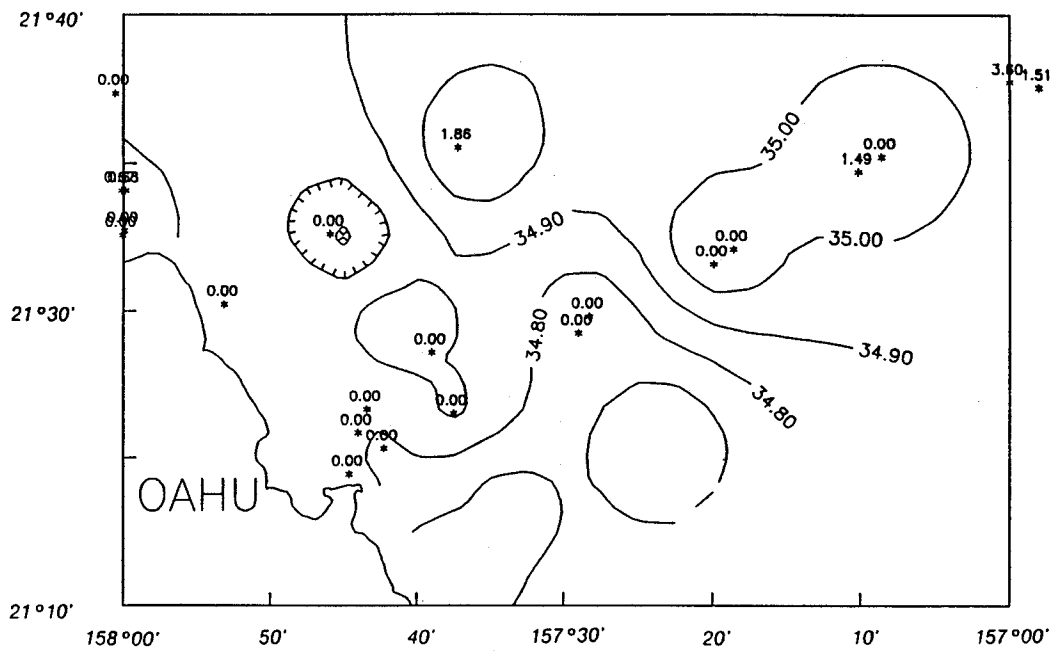


Figure 17.--Continued. (B) Surface salinity contours.

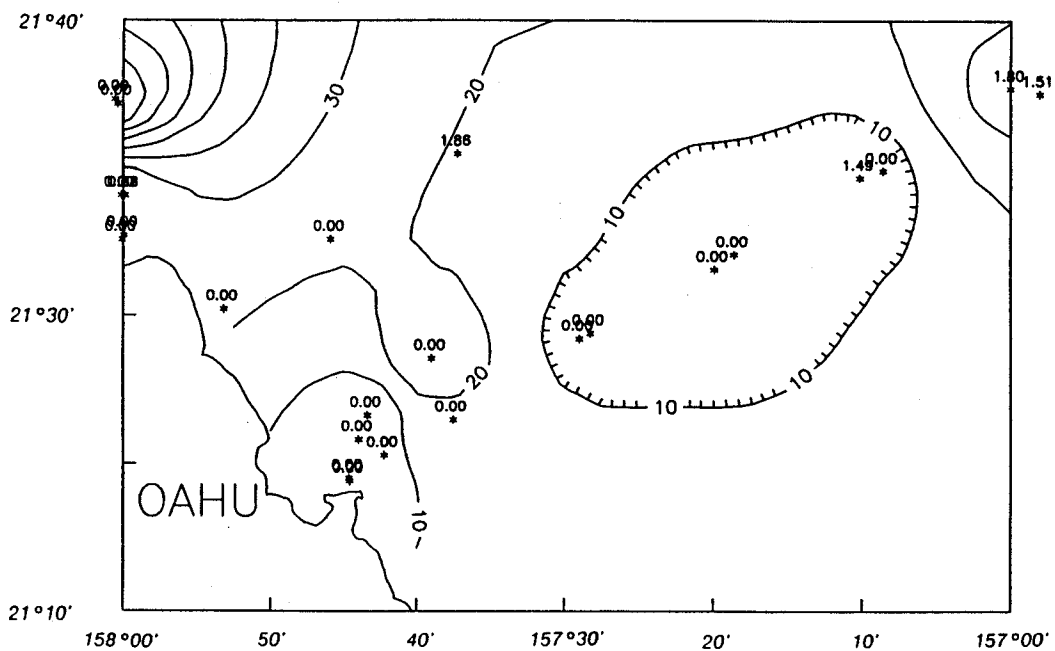


Figure 17.--Continued. (C) Contours of actual surface zooplankton densities.

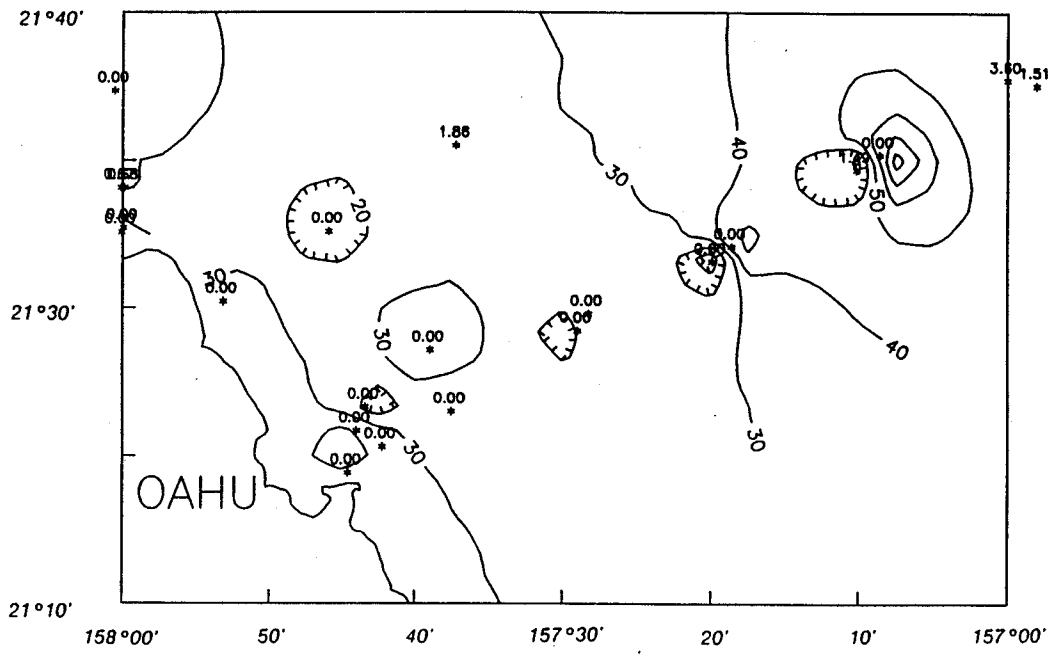


Figure 17.--Continued. (D) Contours of surface larval fish densities.

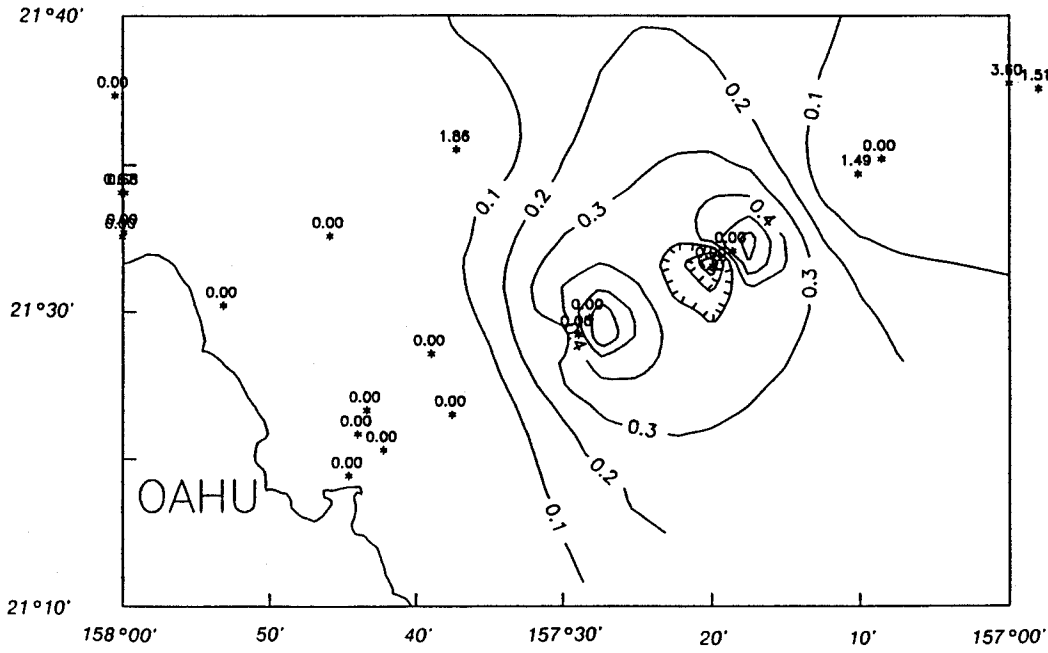


Figure 17.--Continued. (E) Contours of postlarval flying fishes densities.

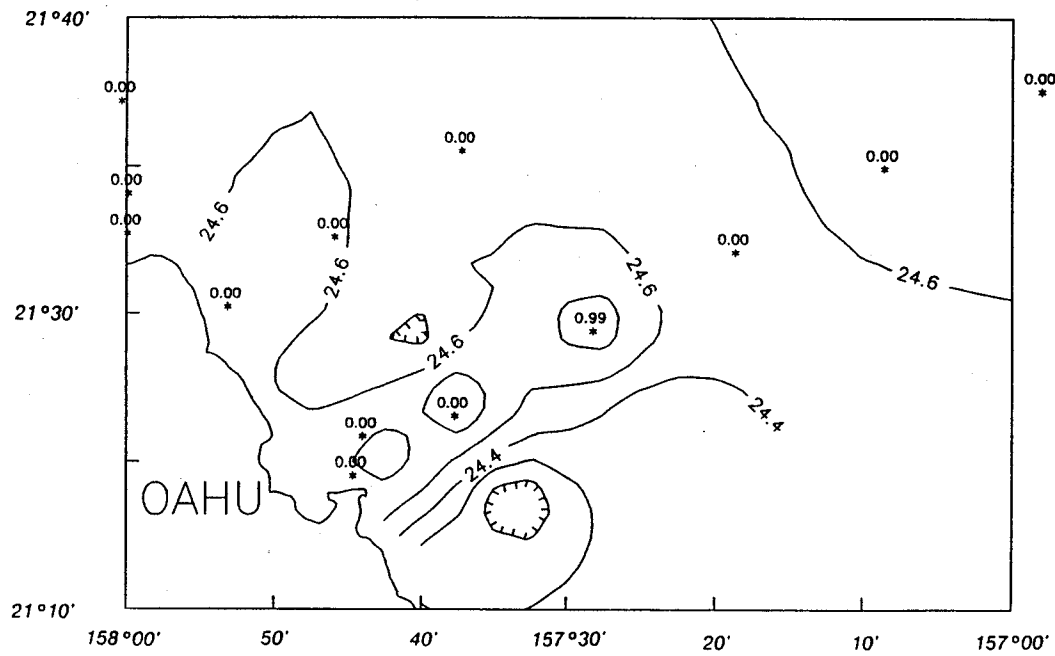


Figure 18.--Densities of larval and postlarval *Coryphaena equisilis* caught in night samples posted on the following contours off windward Oahu, April 1988.
(A) Surface temperature contours.

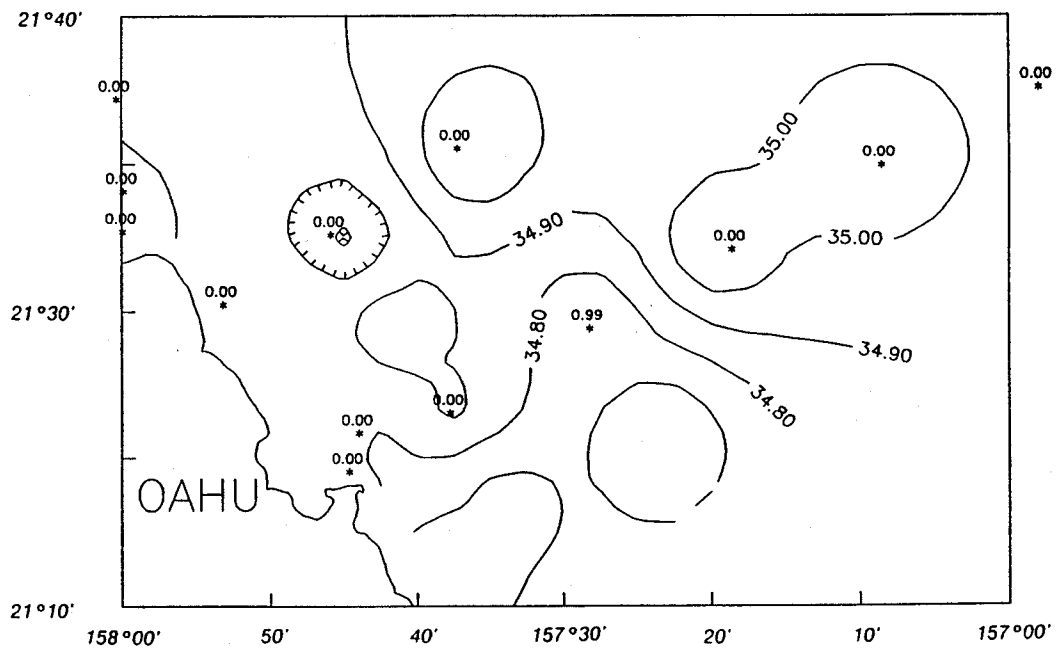


Figure 18.--Continued. (B) Surface salinity contours.

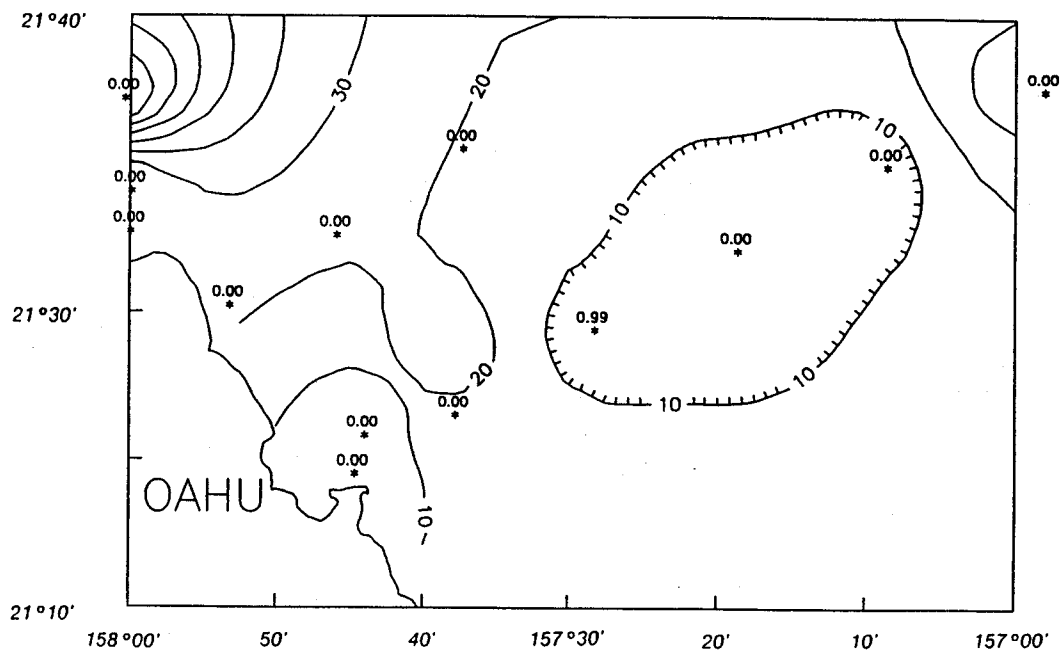


Figure 18.--Continued. (C) Contours of surface night zooplankton densities.

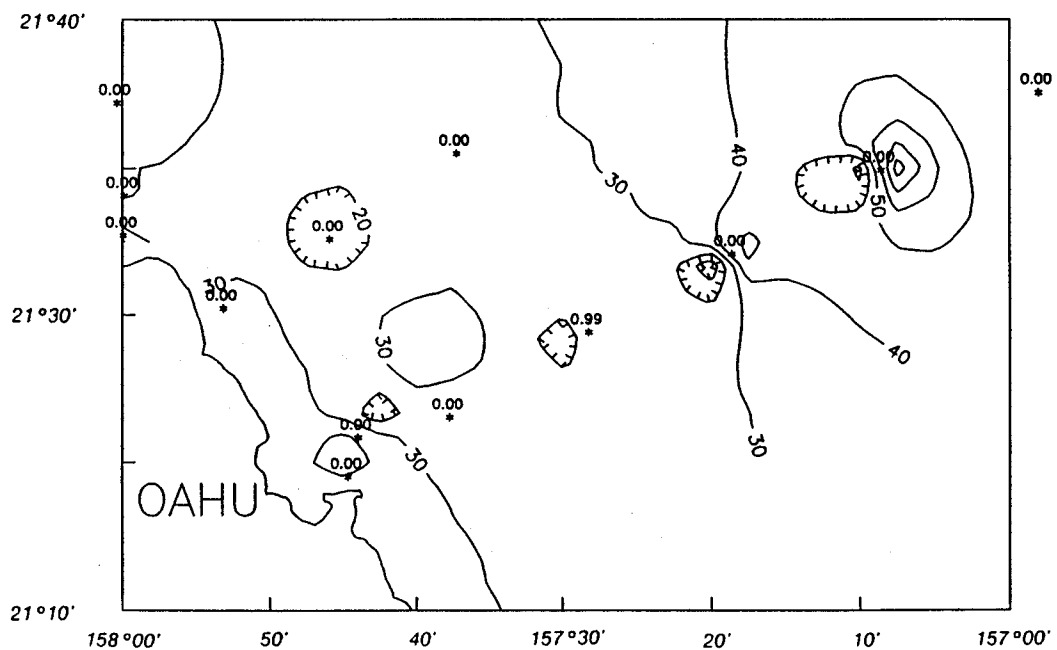


Figure 18.--Continued. (D) Contours of surface night larval fish densities.

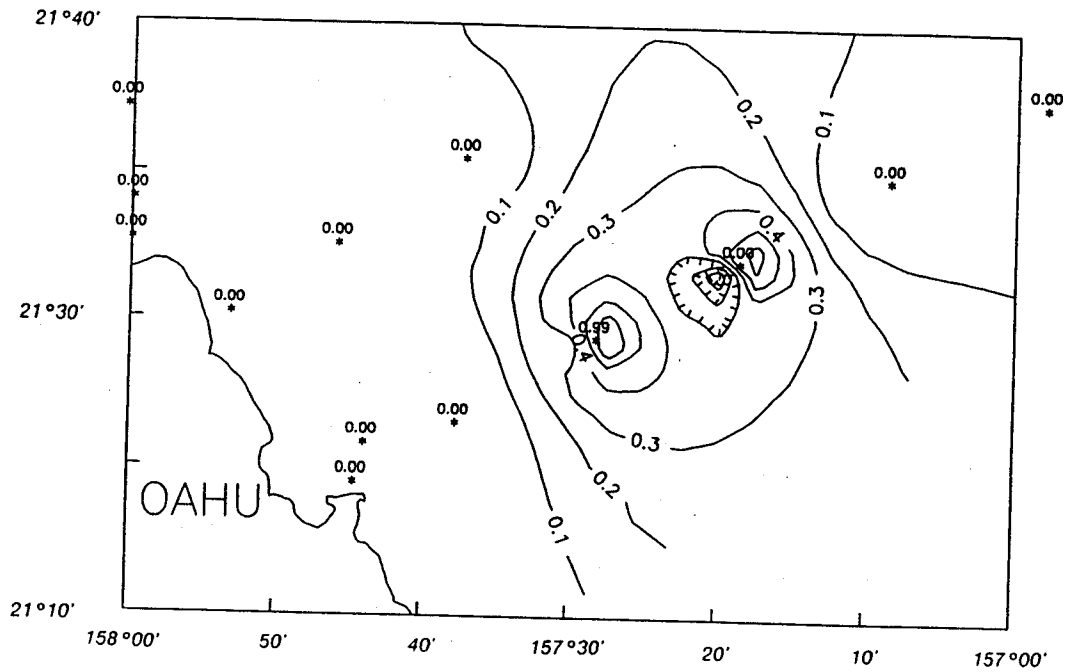


Figure 18.--Continued. (E) Contours of night flying fish densities.

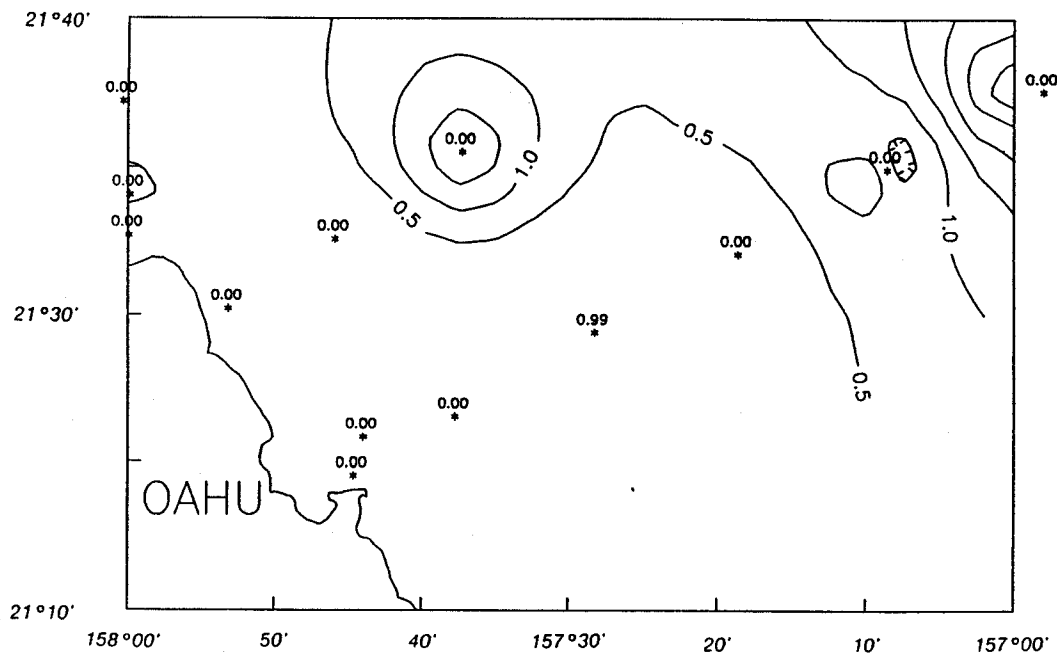


Figure 18.--Continued. (F) Contours of larval and postlarval *C. hippurus* densities (night samples).

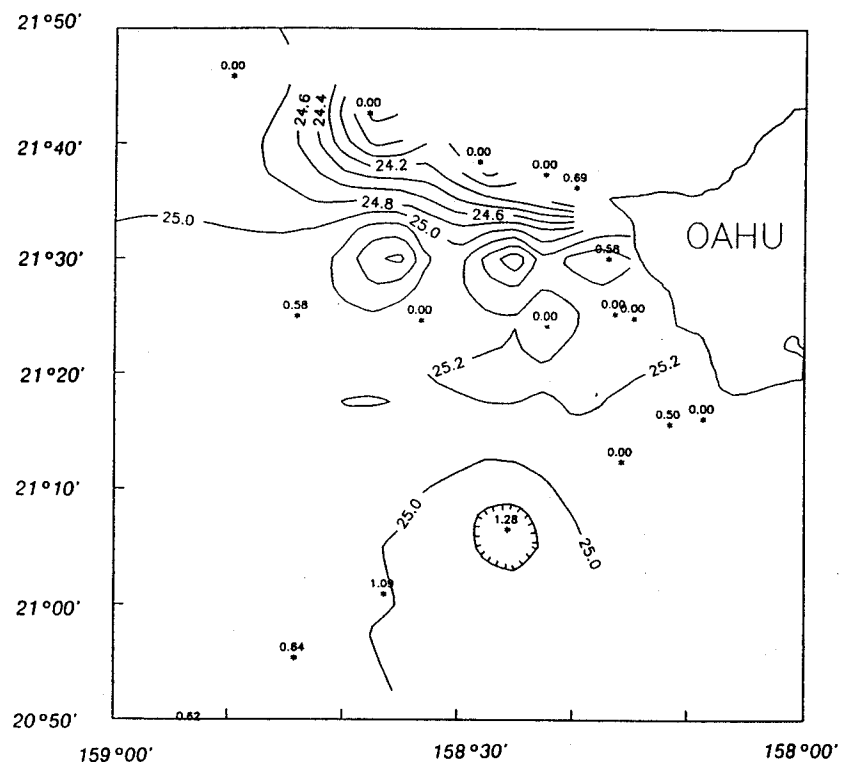


Figure 19.--Densities of larval and postlarval *Coryphaena hippurus* caught in samples posted on the following contours off leeward Oahu, April 1988. (A) Surface temperature contours.

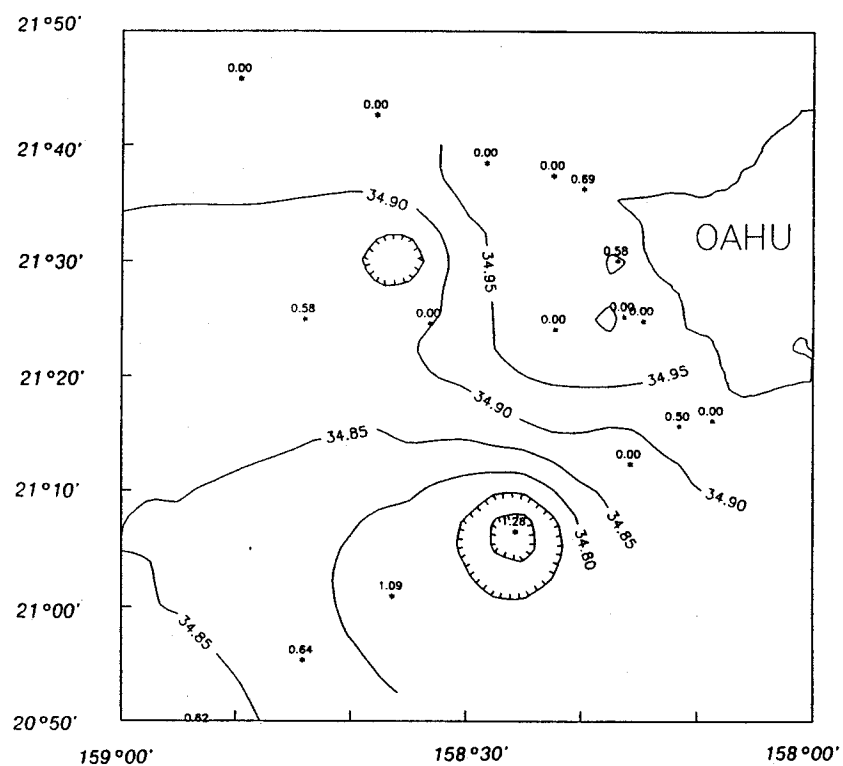


Figure 19.--Continued. (B) Surface salinity contours.

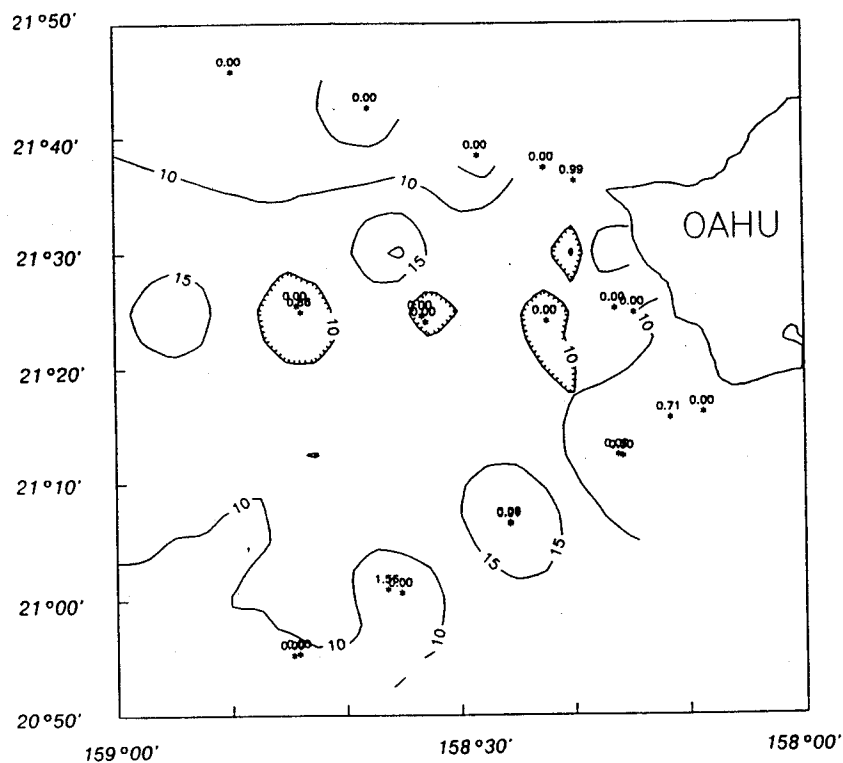


Figure 19.--Continued. (C) Contours of actual surface zooplankton volumes.

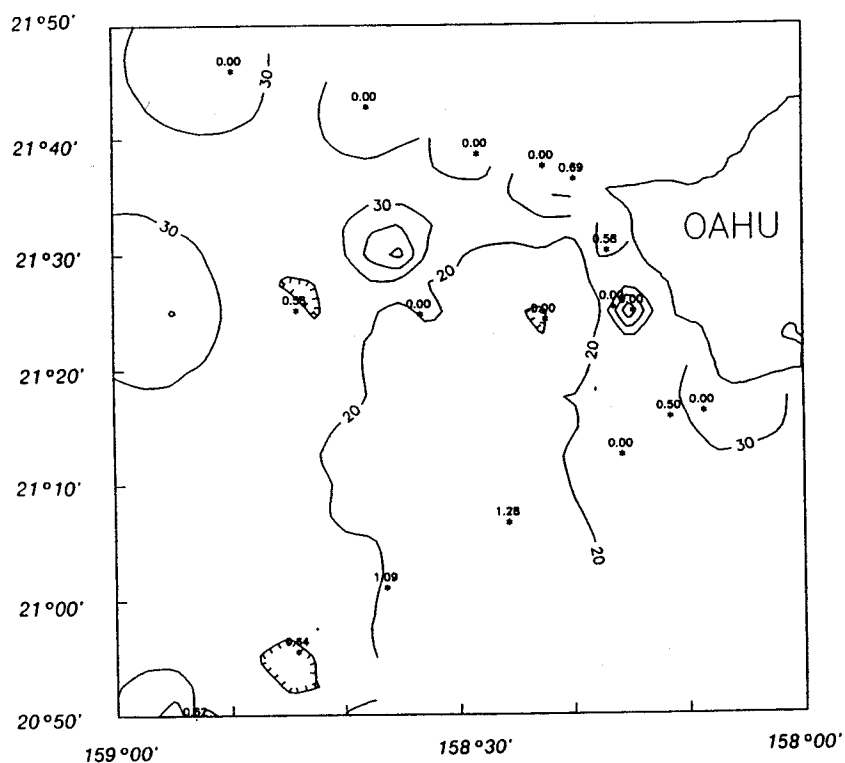


Figure 19.--Continued. (D) Contours of surface larval fish densities.

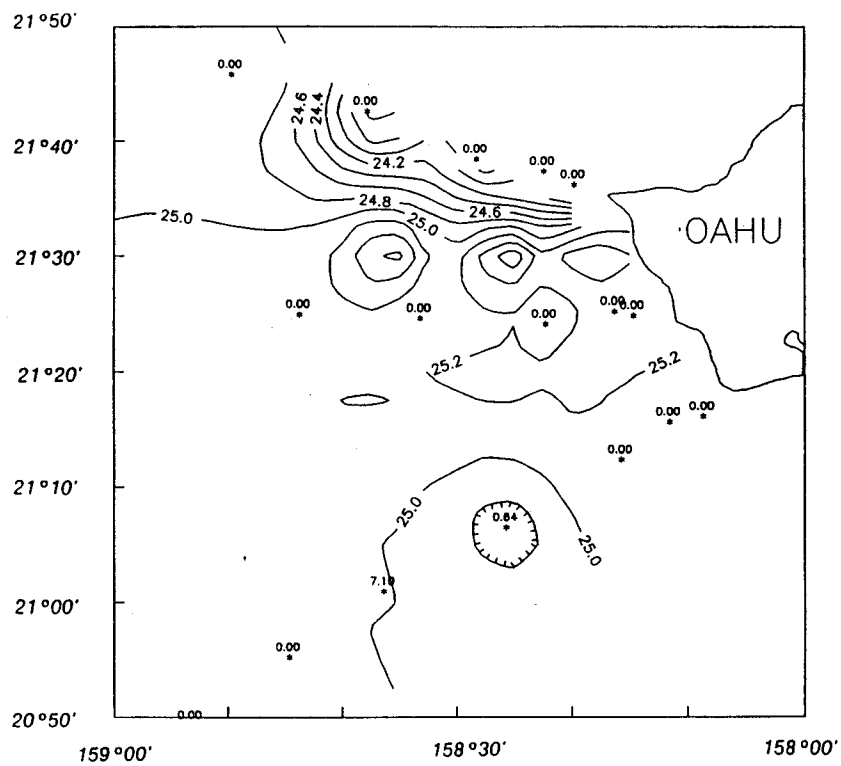


Figure 20.--Densities of larval and postlarval *Coryphaena equisilis* caught in night samples posted on the following contours off leeward Oahu, April 1988. (A) Surface temperature contours.

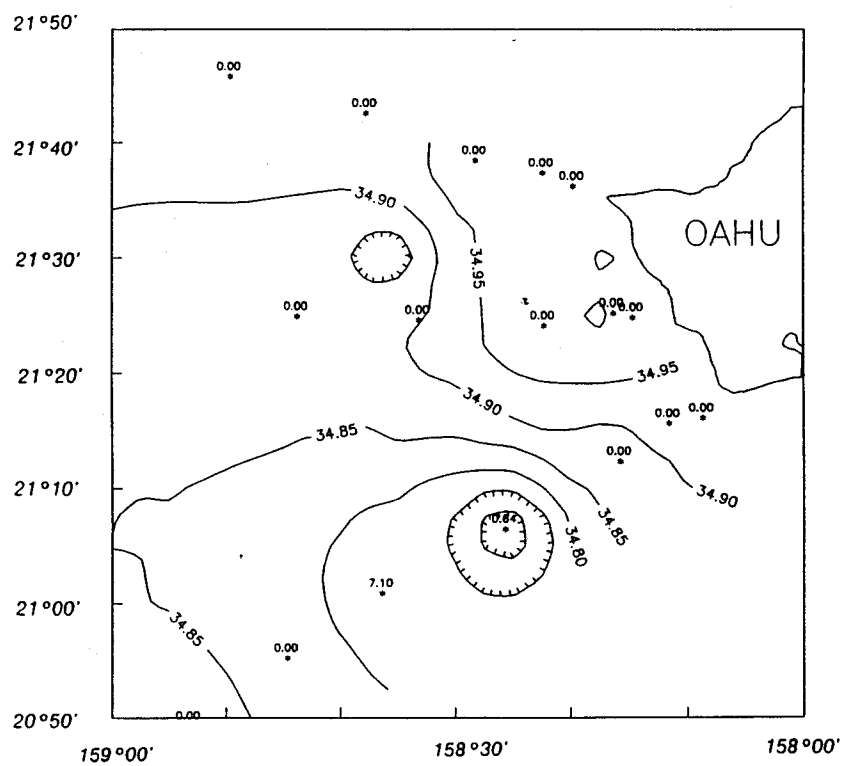


Figure 20.--Continued. (B) Surface salinity contours.

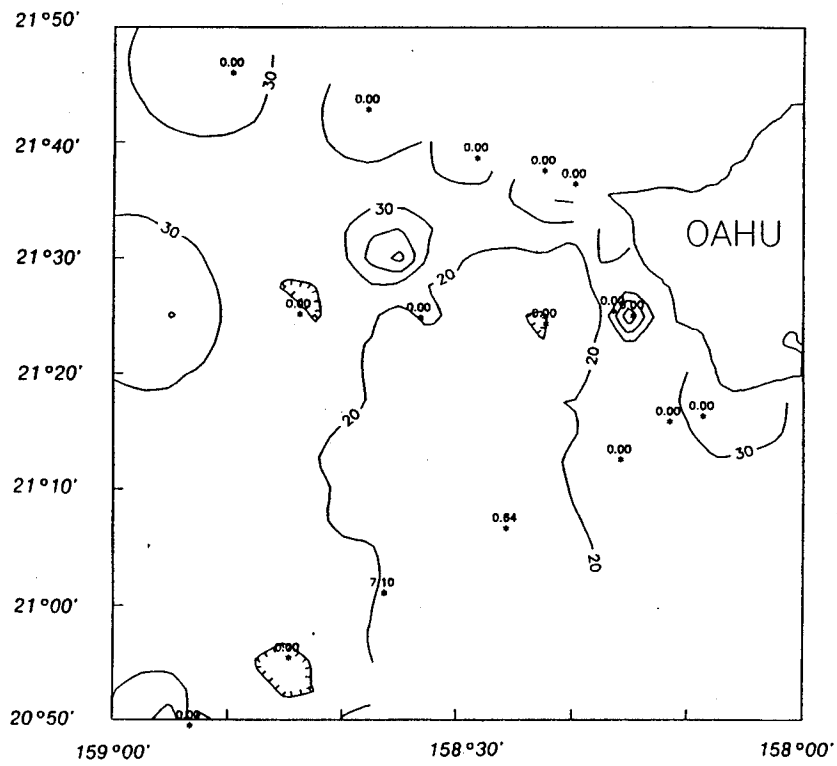


Figure 20.--Continued. (C) Contours of actual surface night zooplankton volumes.

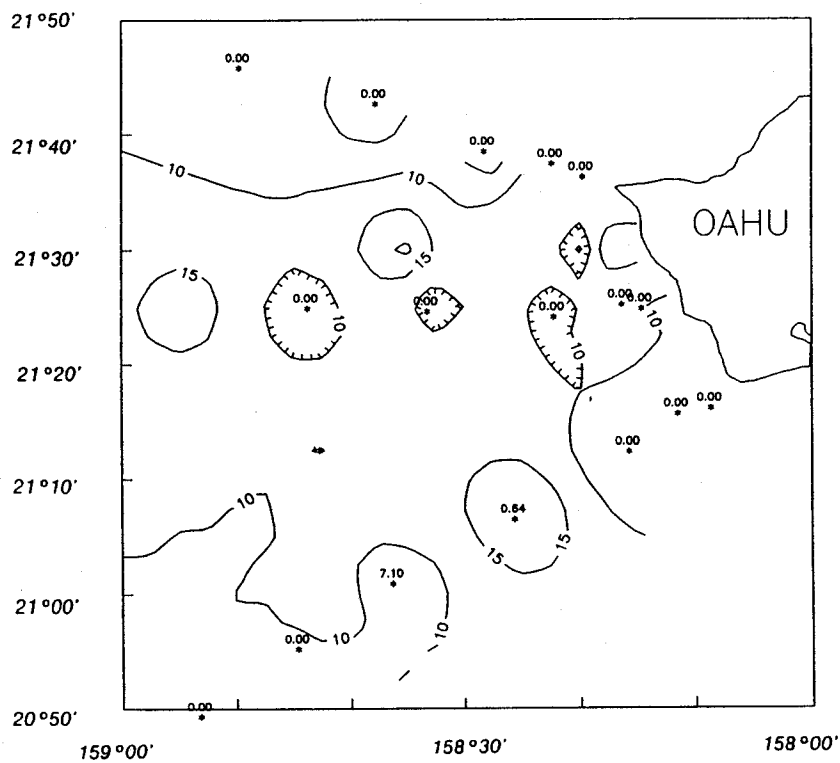


Figure 20.--Continued. (D) Contours of surface night larval fish densities.

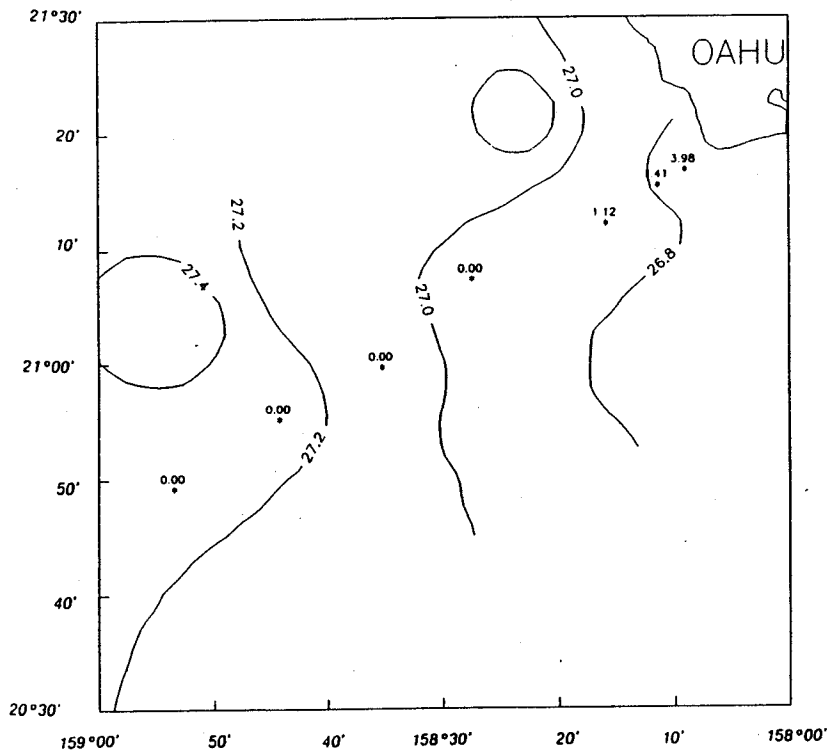


Figure 21.--Densities of larval and postlarval *Coryphaena equisilis* caught in night samples posted on the following contours off leeward Oahu, September 1988:
(A) Surface temperature.

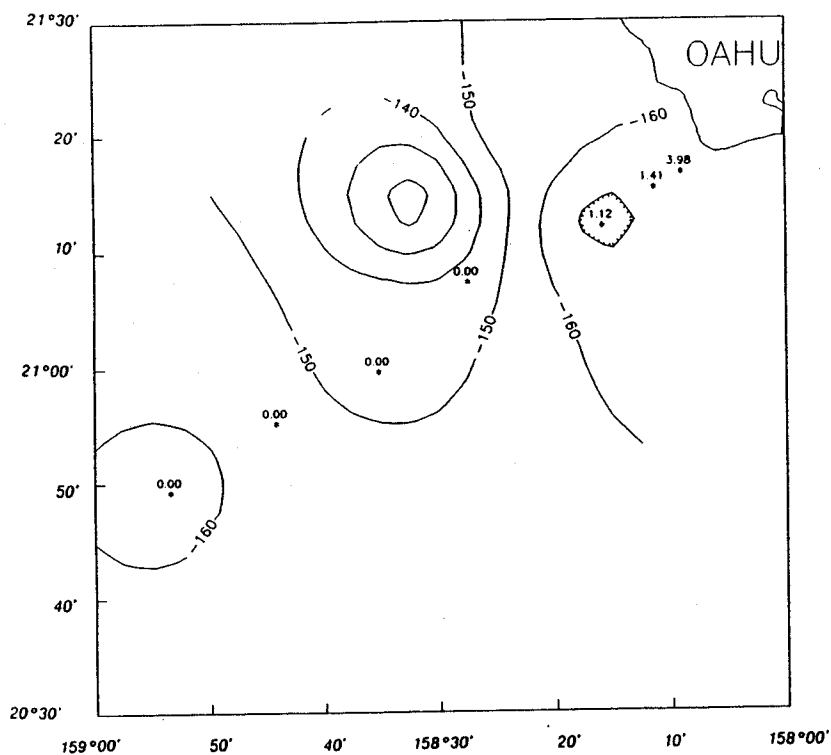


Figure 21.--Continued. (B) The 20°C isotherm depth.

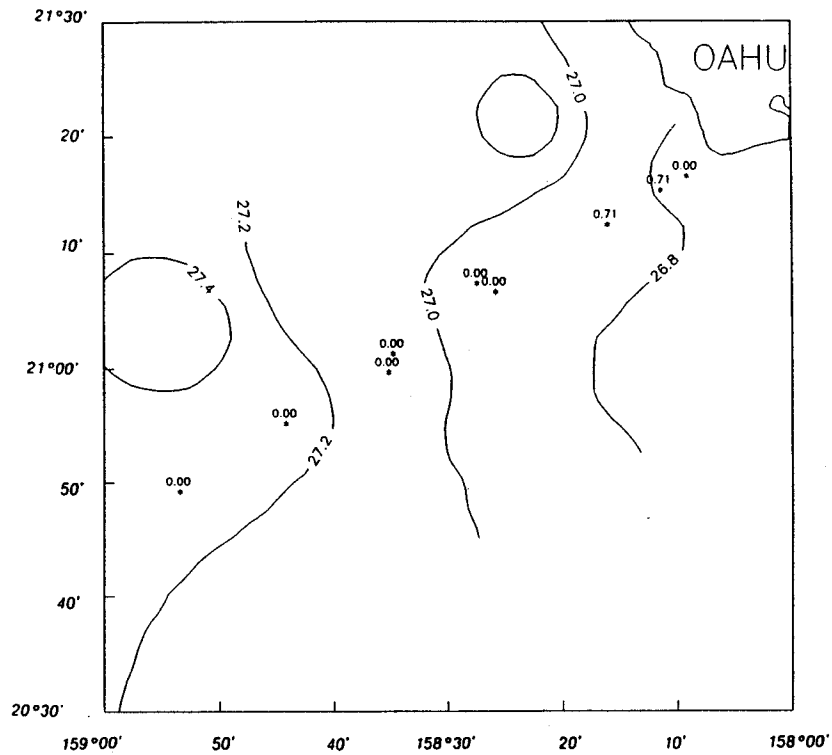


Figure 22.--Densities of larval and postlarval *Corphaena hippurus* caught in samples posted on the following contours off leeward Oahu, September 1988: (A) Surface temperature.

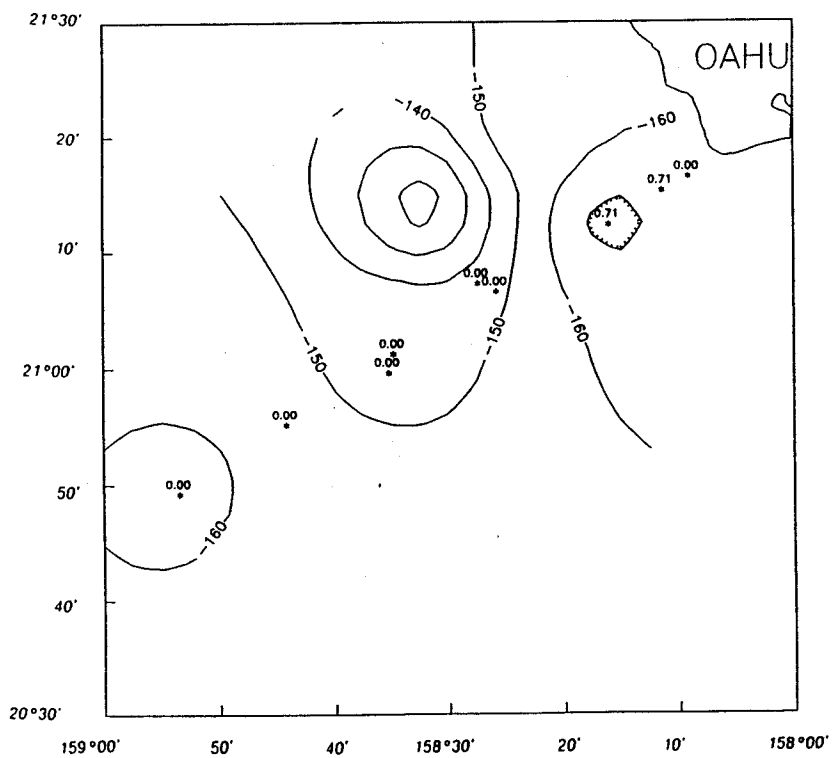


Figure 22.--Continued. (B) The 20°C isotherm depth.

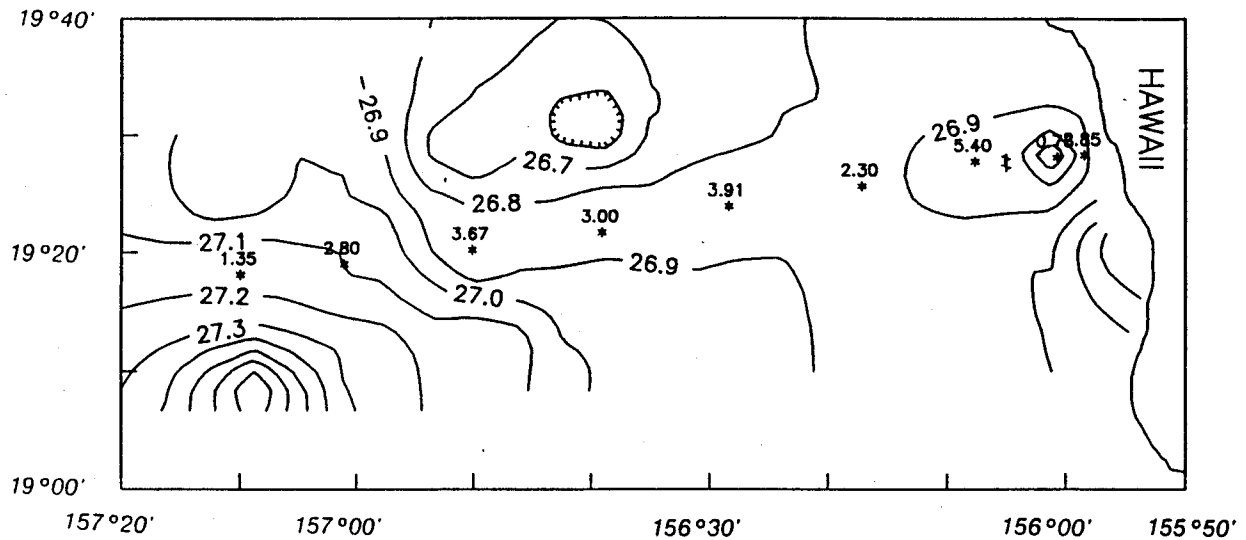


Figure 23.--Densities of larval and postlarval *Coryphaena equiselis* caught in night samples posted on the following contours off Kailua-Kona, Hawaii, September 1988: (A) Surface temperature contours.

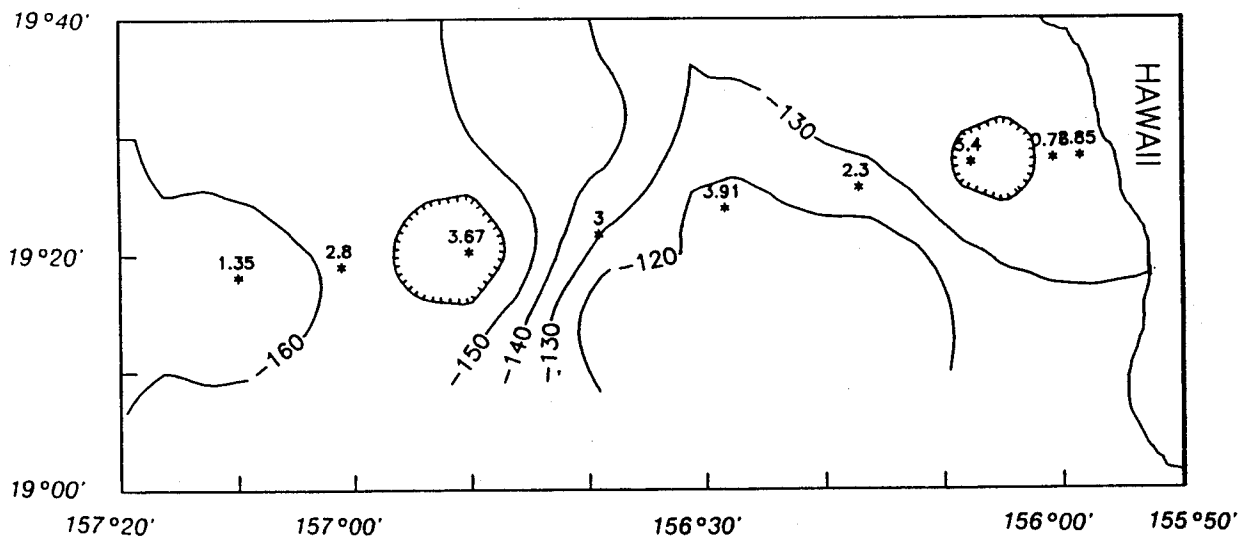


Figure 23.--Continued. (B) The 20°C isotherm depth.

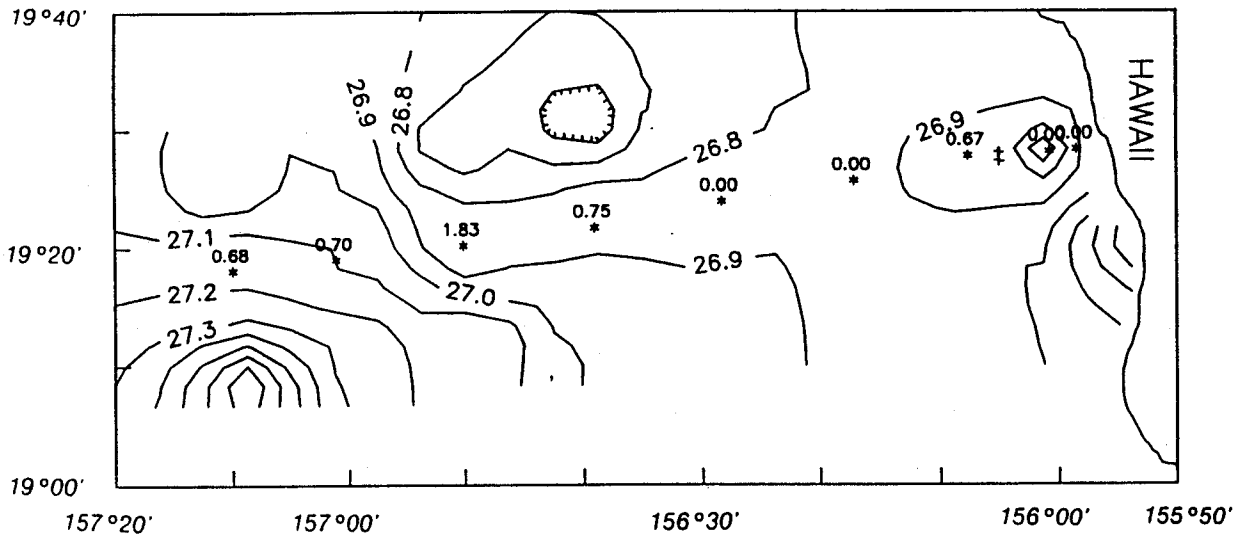


Figure 24.--Densities of larval and postlarval *Coryphaena hippurus* caught in night samples posted on the following contours off Kailua-Kona, Hawaii, September 1988: (A) Surface temperature contours.

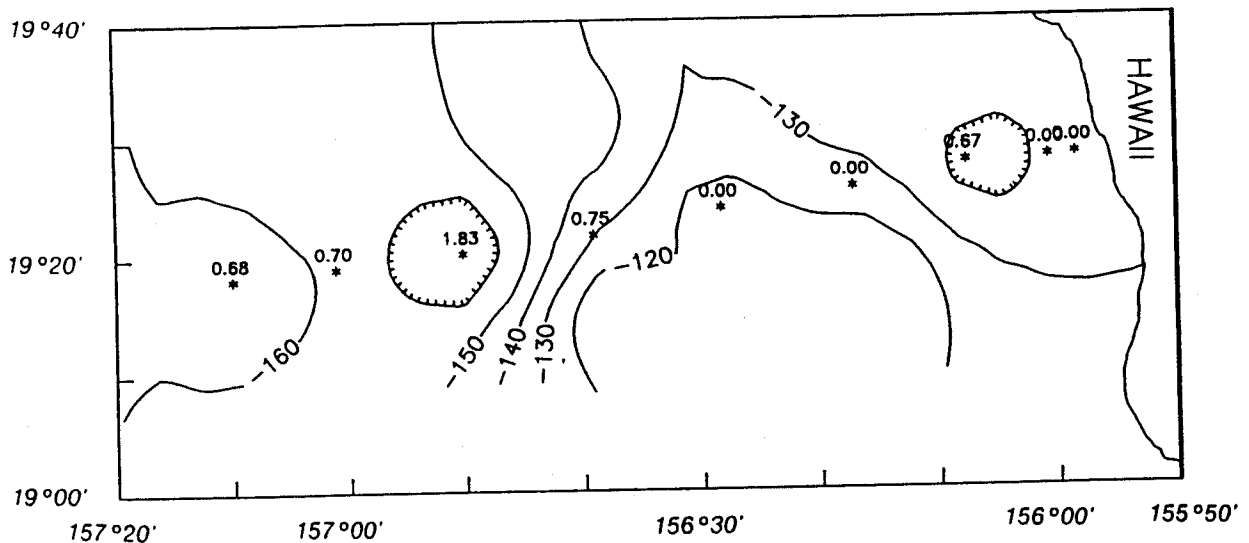


Figure 24.--Continued. (B) The 20°C isotherm depth.

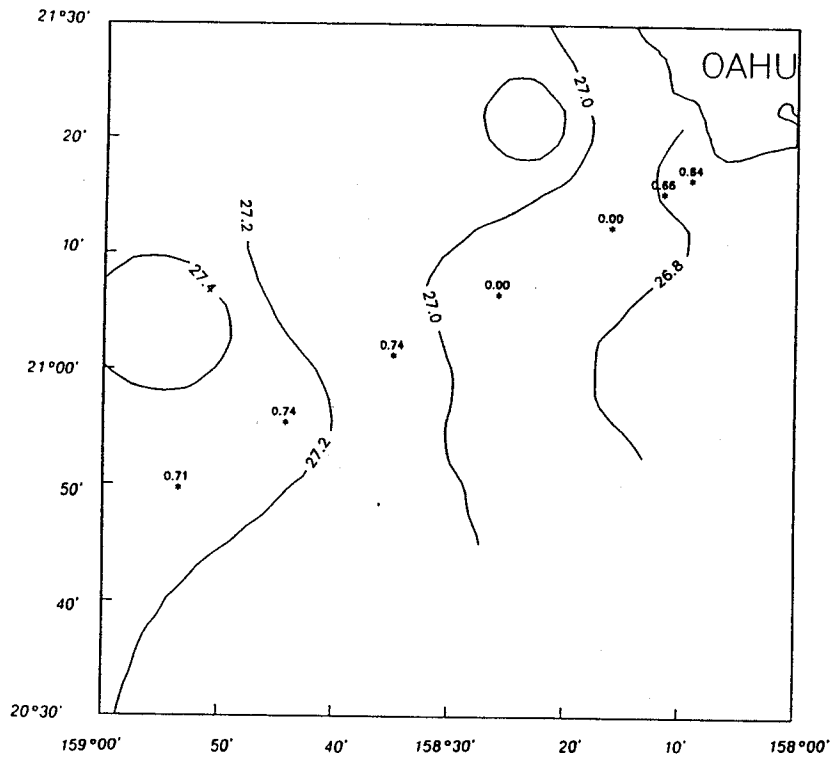


Figure 25.--Densities of larval billfishes posted on surface temperature contours off leeward Oahu, September 1988.

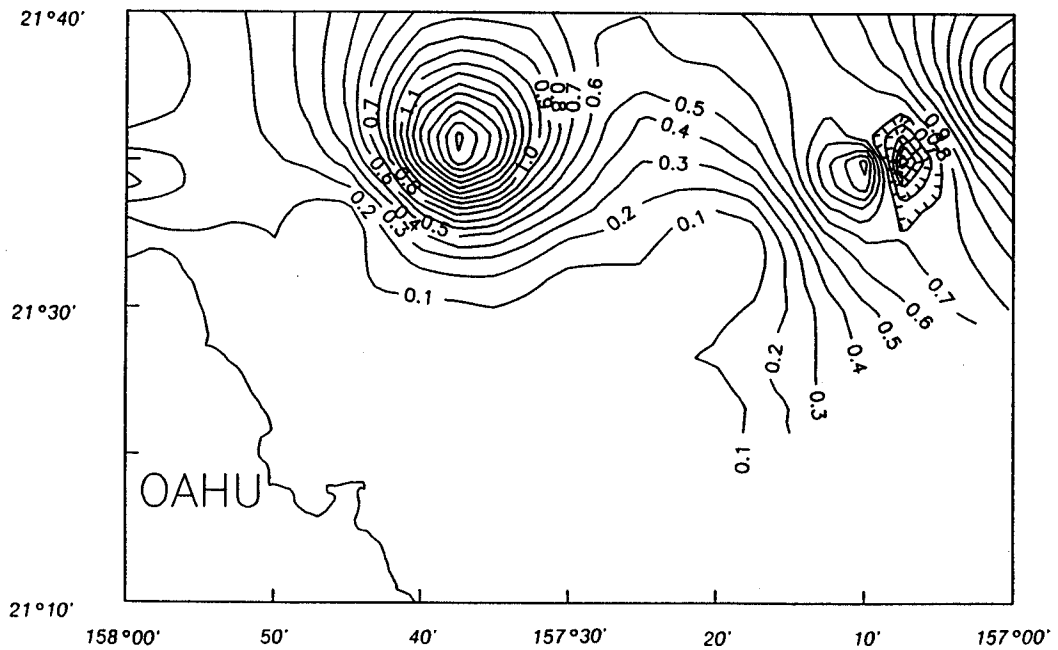


Figure 26.--Contours of postlarval *Coryphaena hippurus* densities in April 1988: (A) Off windward Oahu.

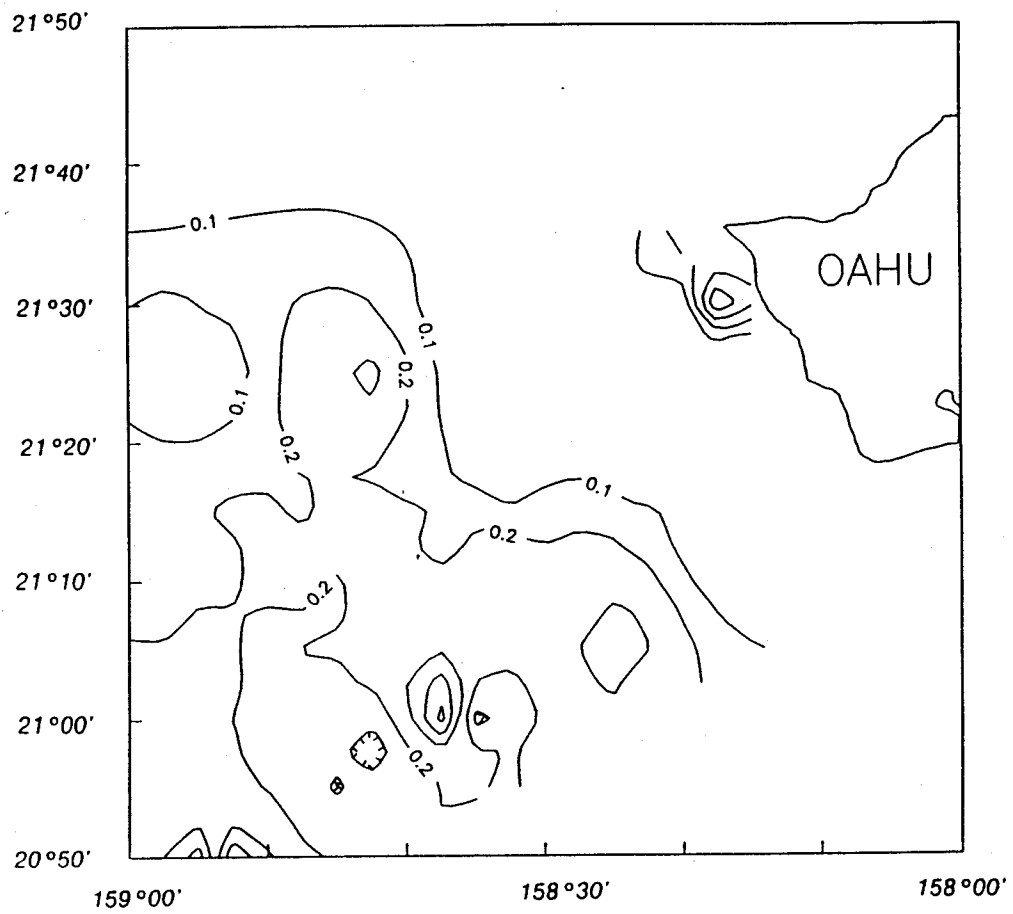


Figure 26.--Continued. (B) Off leeward Oahu.